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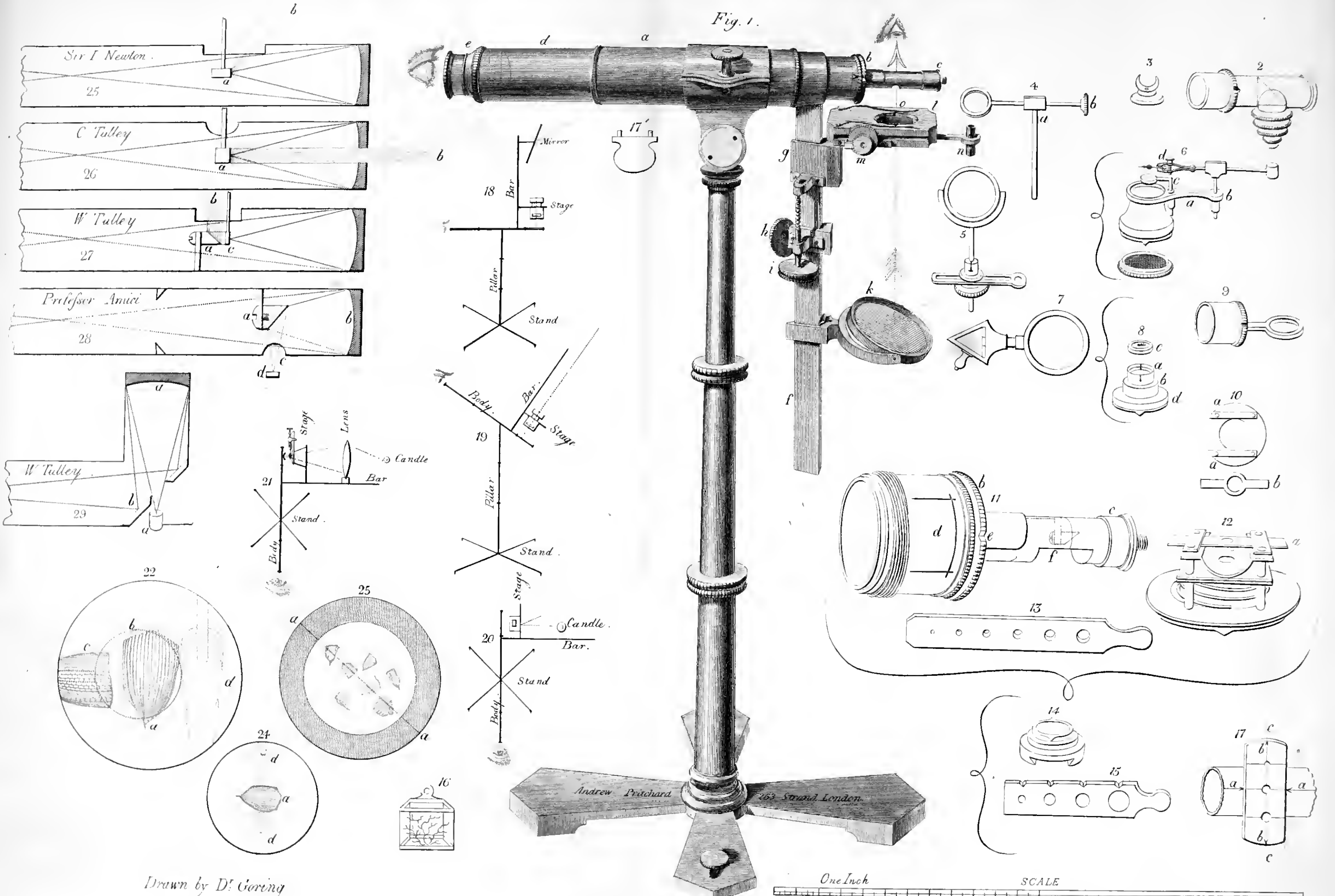
Horizontal Achromatic and Amician Reflecting Engiscope.



Drawn by Dr. Goring

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MICROGRAPHIA:

CONTAINING

Practical Essays

ON

REFLECTING, SOLAR, OXY-HYDROGEN GAS

MICROSCOPES; MICROMETERS;

EYE-PIECES, *&c. &c.*

BY

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PREFACE.

The importance and utility of the modern improvements in Microscopes being now generally recognized throughout Europe by all practical zoologists and botanists*, the present publication seems imperatively called for as a necessary sequel to the "Microscopic Illustrations" and "Microscopic Cabinet," and is intended to supply all the practical information microscopists can require, which is not afforded by those works.

The first chapter contains a description of all the reflecting Microscopes that are worthy of note, and in particular an account of the most improved form of that of Professor Amici, of Modena (the only one which has come into use): and it may fearlessly be maintained, that Dr. Goring has omitted no argument which could be adduced in its favour. To this is attached full and perspicuous directions for its management, in every possible manner in which it can be mounted. In my humble opinion, this chapter is an excellent model for this kind of writing.

* The recent discoveries of the fossil remains of Infusoria, Plants, &c. will cause the geologist also to call to his assistance the aid of the Microscope.

The tract on Micrometers, whatever may be its faults, is the best practical treatise that has yet appeared; and it is worthy of remark, that few theoretical or even practical opticians can determine the foci or powers of small lenses *with any degree of precision:* put a minute lens into their hands, and ask them to tell you what its solar or visual focus is, and ten to one if they can give any thing but a rude approximation to the truth. Now, all difficulties of this kind are obviated; for by his tract, the foci, powers, &c. of all sorts of lenses, simple and compound, as well as those of Engiscopes, can be determined with accuracy. To the description of the various constructions of Micrometers is added that of a new one, for single or compound magnifiers.

The chapter on Monochromatic Illumination contains many curious particulars: that on Solar Engiscopes may be said to be written on a new species of instrument, or one at least not as yet introduced into use, but which may be expected one day to become highly popular with the more refined and fastidious admirers of the wonders displayed by Solar Microscopes.

The chapters* on trying Microscopes and Engiscopes against each other, and that on Eye-pieces, contain much valuable information, and are written in a very forcible style. The tract (Chapter VII.), illustrative of the effects of *large angles of aperture* on the vision of objects, as contradistinguished from

* The opinions expressed in each chapter are those of the writers whose initials are severally subjoined.

magnifying power, touches the very nerve of the question respecting the importance of the modern improvements of object-glasses, metals, doublets, and triplets; the extension of their angular aperture, or *the taking in of a large pencil of light* (free from aberrations) *from every part of the object*, being, in fact, nearly the sum and substance of every thing which has been effected in ameliorating the optical part of Microscopes and Engiscopes; for so far from increasing the magnifying power (as is generally imagined by persons not acquainted with the subject), the principal improvement may be said to consist *in so augmenting the penetrating powers of these instruments, that a very high degree of amplification becomes in a manner unnecessary*. There is also some useful information on Objects in this chapter.

My own essay on Solar and Oxy-hydrogen Gas Microscopes will, I doubt not, receive due attention from the public, being the first account of the latter which has appeared; it will be found to contain a vast body of very useful practical information respecting these highly popular, attractive, and amusing instruments, which may be said to have conferred on mankind a new source of pleasure.

In Chapter XI. I have briefly described a few contrivances for facilitating the observation of Microscopic Objects, and perfecting the mechanical part of instruments.

Correct Drawings of Microscopic Objects are exceedingly valuable; they are every day sought after

with increasing eagerness; and as my friend, Mr. Bauer, has made more of them than any other person in England, it appeared to me highly desirable to present the reader with an account of the method pursued by him in their production. For this purpose, I have been favoured with a short essay written by himself, and feel confident it will be perused with much interest. The other paper in the Appendix, by the Rev. J. B. Reade, on his new method of Illuminating Microscopic Objects, will be found highly useful, either for investigation or amusement; with it, even the most fastidious may employ a miscroscope without excitement from light, as in the ordinary illumination, while it is equally available for the larger class, or for the scales of the Podura.

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CONTENTS

OF THE

OPTICAL SECTION OF THE MICROGRAPHIA.

Chap. VII.

APPENDIX.

MICROGRAPHIA.

CHAPTER I.

HISTORY AND DESCRIPTION OF THE AMICIAN REFLECTING ENGISCOPE.

WHILE one sect of Microscopists is pragmatically employed in the production of *fancied novelties,* and not unfrequently of *downright retrogradations* in the structure of Microscopes, another party seems sturdily determined that there shall be nothing new under the sun in these latter times: we may rack our brains till they are addled, invent and excogitate all sorts of wonders, ay, and get rewarded by some learned body for our pains, and lo! it is certain to be found out in the end that we have merely resuscitated some old thing which the ignorance, or want of recollection, of the public had overlooked, and that our utmost endeavours have only succeeded in dressing it out in new habiliments, or engaging it in some new occupation.

When Professor Amici, of Modena, *invented* his admirable reflecting Engiscope, (for it cannot be pretended that we ever had a reflector really capable of *practical* application before,) the spirit of detraction instantly exclaimed that he had *merely reversed a Newtonian telescope made on a small scale,* and of course refused to concede the merit he had so richly earned in inventing and introducing into use what every candid person must allow to be a *real novelty.* Sir Isaac Newton never recommended any such adaptation of his telescope to the purpose of acting upon diverging rays, but merely a concave metal to form an image, and an eye-glass to view it with, being

in fact the simplest kind of reflecting microscope which can possibly be constructed, and the best also, if it could but be *easily* applied to the examination of minute objects; which, however, is not the case. (Vide fig. 25.) In fact, it is in the exterior only of the Amician microscope that there is a *primâ facie* resemblance to a Newtonian telescope, for the form of the concave metal and the situation of the radiant point are so totally different, as to constitute a new instrument.

It has always been remarked that the English invent nothing, but improve upon every thing; and the Amician reflecting Engiscope may, in its perfect state, certainly be considered as a fine sample of English improvement on a foreign invention. For, though Professor Amici joins to his acquirements as a man of science an admirable genius for mechanics, and is, in fact, one of the best workmen the continent can produce, yet the instrument was turned out of his hands in a very rough and ineffective state, owing to the concave metal being of too long a focus, and too small an angle of aperture, and the diagonal one of too large a diameter, which caused it to intercept too large a quantity of light from the other, leaving only a narrow rim of reflection to enter the retina, which occasioned a disagreeable nebulosity in the middle of the field of view, unless the eye-glass was of great depth; the mounting was, moreover, very deficient, and greatly disabled and cramped the powers of the instrument. The original dimensions of Amici's Engiscope were the following:—Elliptic metal 1 inch aperture, and $2\frac{6}{10}$ inch focus; diameter of the diagonal $\frac{1}{2}$ an inch; length of tube 1 foot; and however well such metals may be worked, it will be found impracticable to render them capable of exhibiting even ordinary minute objects as they ought to be shewn, much less tests.

I shall now proceed to describe the instrument *in its effective form*, as constructed at my suggestion, with the *final* improvements in the mechanical part, which my worthy coadjutor, Mr. Pritchard, and myself, have effected in it.

To begin from the foundation : — The stand or pillar of the Engiscope is not unlike those of small spy-glasses; it grasps the body of the instrument by means of a split socket, as they do, and will readily serve as a stand to a 20-inch glass, if required: the peculiarities of it I shall now notice. The pillar is screwed on to a solid *cruciform* stand:—it is well known to every cabinet-maker that a claw table stands much more securely on four legs than on three, and is much less liable to be overturned; of this any person may easily satisfy himself; and though a table on three legs is always sure to rest truly on an uneven surface, one on four may be made to do so likewise by means of an adjusting screw applied to one of the legs, made purposely a little too short, and, moreover, will not require to be made so massive, or to have its feet sprawled out so far, in order to procure a given degree of stability. Now the Amician Engiscope requires to be raised to a considerable height, in order to come to the height of the eye without a scaffolding of boxes, books, or pieces of wood, &c.: nothing can be more agreeable to use when it is on a true level with the eye, or more uncomfortable when it is not; on this account the cruciform stand seems to be peculiarly suited to it. At the same time I freely admit, that if the legs are wanted to be made *to fold up* together, in order to pack in a small compass, the tripod is the preferable construction, for the cruciform must be made of *one piece*. Mr. P., of course, makes them to suit the fancy of purchasers: I have little doubt that he would, to oblige a good customer, mount an instrument on a mop-stick, or the top of an old brass candle-stick, as Sir I. Newton did the original of his telescope. It will be observed that there are two joints in the pillar, like those of a pull-out telescope: these are composed of tubes, the recipient part of which is split, and screwed on the outside, and firmly grasps the internal tube by means of the pinching milled heads, so that the whole is as strong and solid as if made of a single tube. As will be seen by reference to the scale, the instrument may be

elevated to the height of 18 inches, if required. All the particulars I have described are sufficiently well represented in Plate 1, fig. 1; the adjusting screw for the fourth foot is seen in front. Fig. 17 is a key for tightening the cradle-joint at the top of the pillar, so that the body may be firmly fixed in any degree of inclination without swerving when turned round in the split socket.

The body (*a*) has nothing very peculiar about it; it has the usual eye-tube (*d*), into which is screwed the eye-piece (*e*), consisting of two glasses on the Huyghenian principle, but in the *lower powers* further separated than in the regular construction, to accomodate them to the metals: it is difficult to procure a field of view of more than 20° with a very shallow eye-piece. acting with a short body, if a maximum of distinctness is required. Not unfrequently the *edges* of the field of view with *low powers* are rendered dark and shadowy, or altogether invisible, owing to the hole in the side of the tube of reflectors (fig. 28, *c*.) not being sufficiently opened out. The same effect is even, to a certain extent, sometimes produced by the hole in the stage being too small, or closed up partially by the traversing plates. The foci of the anterior glasses of the eye-pieces, of which there are usually three, are 3-4ths, 3-8ths, and 3-16ths of an inch; the powers given by which of course depend upon the depths of the metals they are used with, and also upon the elongation or contraction of the length of the body, by means of the eye-tube. *b, c,* is the tube containing the metals; a section of it, fig. 28, shews them of the full size for one inch acting focus, *in sitû*: *b*, is the elliptic one; *a*, the plane diagonal, *c*; the hole in the side of the tube to admit the rays from the object, *d*, the radiant point, or object itself. The rays proceed from the object in the manner marked in fig. 28, and are reverberated into the opposite focus of the ellipse, where they form an image between the two eye-glasses, which is viewed by the eye through the anterior glass.

On the outside of the tube of reflectors, at *b*, will be re-

marked a lappet, or segment of tube, the use of which is to lap over the hole in the side of the tube, to keep out dust and damp, &c., when the reflectors are not in action: for the same reason a cap is made to cover the open end of the tube, when removed from the body. A circular line is also turned on the tube, passing exactly through the centre of the hole in the side, as a rough guide for placing the object in its proper place.

It here becomes necessary to say somewhat concerning the manner in which the tube of reflectors and the body of the instrument are attached to each other: this is effected in the ordinary manner in which the component tubes of a pull-out spy-glass are connected with each other. Every one must have observed that the tubes of spy-glasses rather get tighter than otherwise from age and use, owing to the partial oxidation of their surfaces; moreover, if well executed, a tube consisting of a number of pieces is just as stiff and straight as if formed only of one. In this way, therefore, are the tubes of reflectors fastened to the main body; one of them, of the full size, is seen at fig. 11, with the spring-joint* (*d*), which will, I doubt not, be instantly recognized by any optical turner†. The only peculiar point necessary to be attended to is to form a notch, or a mark of some kind, on the milling of the sliding tube (*e*), which must be made to coincide exactly with another on the neck of the body, as may be observed in fig. 1, in order that the metals may be always affixed so that the prolongation of their axis and of the body may be in the line of the bar. Too much care cannot be bestowed on this circumstance, for if the plane of the stage and object presents itself obliquely to the metals, their performance will be seriously deteriorated.

* One of these, of course, suffices *for the whole of the tubes*, and always remains screwed to the neck of the body.

† I think the joints of flutes, clarionets, &c. might be made with great advantage on this principle, and would not be at all liable to get out of order; a little bee's-wax and suet would render them perfectly wind-tight, though I suspect if the tubes were carefully drawn, and merely wetted when put together for use, the wax would not be required.

f, fig. 1, is the triangular bar of the Engiscope, soldered to the neck of the body, which, with all its apparatus, is much like that of other engiscopes. Its mirror is plane on one side, and should be a dead white surface on the other. I do not hold with concave mirrors; they always produce an indistinctness in vision, along with an increase of light, when used with transparent objects, and for opaque ones they are not wanted, as the condensing lens, fig. 7, acts much better, either used by itself or in conjunction with the plane side of the mirror, as circumstances may require. The stage *(l)* is undoubtedly the best yet contrived for giving traversing motions, being the celebrated combination of rack and screw work, worked by the two concentric milled heads at *m*, invented by Mr. Tyrrell. The small anterior head gives a motion to the object in the line of the body, the other in the contrary direction; both are under the command of the finger and thumb of the right hand, and both may be moved together, giving a diagonal motion. The said stage is removable at pleasure, from the triangular socket (*g*) being made to lift out.

To the triangular socket *(g)* is appended that which carries the clamping screw *(h)*, and the adjusting screw *(i)*, by which the object is brought into the focus of the Engiscope.

Fig. 2 is the tube which carries the aplanatic object-glasses belonging to the instrument; the rectangular prism, which enables them to act with the Amician, may be seen in dotted lines. Where several object-glasses are screwed together, they ought to be made of decreasing diameters, as shewn in the plate; the anterior ones (which are always of shorter foci than the first screwed on) being the smallest, so that whenever one objective is screwed on before another, it shall always be of less diameter than that to which it is attached, and thus *leave space for the illumination of opaque objects.* When all are made of the same diameter, in the usual manner, it is impossible to illuminate opaque objects shewn by them otherwise than by a cup.

Fig. 3 is a silver cup which is fastened on to the tube of

reflectors by a clasping piece of brass, the perforation in it being made to coincide with that in the side of the tube. Each pair of metals capable of acting upon opaque objects has one adapted to it.

Fig. 4 is an illuminator for opaque objects, about an inch focus: its stem is passed into the spring tube *(n)* carried by the arm attached to the under side of the stage; it has a motion upwards and downwards in the tube, and likewise a rotatory one; the lens also can be turned round in its socket *(a)*, by means of the milled head *(b)*. Nothing, in my opinion, can be a greater blunder than to give these sort of things *a greater latitude of motion than is really requisite*, by means of cradle-joints and balls and sockets, which only render them more difficult to manage, and increase the expense of their construction. By the by, all sorts of needles and pins, &c. ought to be made of brass, or, what would be better, of gun-metal; if made of steel they soon rust by being handled, and then move very stiffly and awkwardly in their sockets.

Fig. 5 is another illuminator for opaque objects, intended to co-operate with that just described, and also to act by itself along with the object-glasses and the metals of long focus.

It is about $2\frac{1}{2}$ inches focus, and is passed into a spring tube travelling on a slide, with a pinching screw underneath, by which it is adjusted at a proper distance from the object, or the second illuminating mirror. It is represented in a detached state, but fixes to the under plate of the stage on that side opposite the milled heads.

Illuminators and burning lenses present much analogy to each other, the caustic and illuminating power of each depending, first, upon their actual diameter, and, secondly, upon their angular aperture: thus a burning lens, even of 2 feet diameter and 4 feet focus, does not exert any great caustic power alone, because, though it draws a vast body of calorific rays together, it does not condense them into a sufficiently small space. But let a second lens be interposed at ten inches from the focal

point of the first, and of sufficient diameter to catch the whole cone of rays proceeding from it at that point, and converge to a focus perhaps only six inches distant from the small one, and we shall soon see what an enormous increase of caustic power will be the consequence. On this principle the two illuminators are combined; the first is only of an inch diameter, but might be made larger to increase the effect, for the vision by the Amician Engiscope is so dark and sombre on opaque objects as to require all the help from illuminators which can possibly be given to it. Every one must, I think, have remarked the intense illumination given by silver cups acting with illuminators of large angular aperture, which is, in fact, an example of the intrinsic brightness produced by a primary lens having its light condensed by a cup placed at a proper distance from it; though a silver cup can never reflect so much light as a lens of the same focus and aperture can transmit, acting in lieu of it.

It might perhaps be worth while to construct an illuminator of two lenses placed at a proper distance from each other with relation to their foci, (somewhat after the fashion of those opera-glasses which are worn about the neck,) having no tube, but mounted on a bar, the largest being made to travel on the bar by means of a socket, and the small one to fold down; the bar must be equipped with a cradle-joint attached to a stem to be passed into the spring tube of the slide.

Fig. 6 is a raised stage to come up to the level of the tube of reflectors, since the primary stage itself cannot easily be made to do so: it has a sunk rim turned to receive a watch or plane glass, black and white discs, &c., like other microscopes, it is also convertible into a black box for viewing certain opaque objects when closed at the bottom by the part (*e*), which is covered on the inside with black silk velvet. (*a*) is an arm made for convenience to revolve round on a shoulder at the top of the stage, and even to remove altogether at the pleasure of the observer; at the end of the arm is a sprung

tube to receive the needle (d), which is furnished at one end with a miniature vice to grasp pins, at the other with a small cylinder to act with silver cups. At c is a small black velvet ground, which is employed when opaque objects, not attached to discs, are to be seen by silver cups, in order that their minutiæ may be displayed to the greatest advantage; the more sombre and obscure these are, the greater is the necessity of an intense black ground to contrast and draw them out. The aforesaid little ground serves the important purpose of keeping all direct rays from the illuminating lens from getting into the Engiscope, so long as it remains in the line of the axis of the metals; but if the traversing plates of the stage are called into *full* action, it must evidently fail in this purpose; they must therefore be quiescent, or nearly so, and the observer will have to move the object about by means of the needle, which, having no cradle-joint, or ball and socket, I know by experience he may *easily* do, giving *a small final motion only* by means of the screws. If, however, it is determined that the traversing plates shall act to their full extent, (*which, by the by, will be sure to cut off some of the light coming from the illuminator,*) then the wire carrying the disc or black ground must be made to fix to one of the arms of the stage: then it will probably happen that *the traversing motions will carry the object away from its influence;* so, upon the whole, I think it is best as I have arranged it. Different sizes of discs will be required to suit different cups.

Fig. 7 is the illuminator co-operating with the silver cups.

Fig. 8 is a species of raised stage, which may be made serviceable for many purposes, but is especially contrived for the reception of test-lined objects, both transparent and opaque; d is a piece of brass fitted to the aperture of the stage, and attached by two catches, corresponding to the nicks in the superior plate; b is a milling attached to a piece of turned work, having in its upper portion a piece of sprung tube with a sunk margin (a) adapted to receive the disc (c), of which a magnified representation may be seen in fig. 23.

These circular object-holders may be made of ivory, having a disc of talc glued to one side, and another kept down by a ring over it, between which the object is to be included in the usual way; the side on which the ring does not appear being placed uppermost. The scales are to be examined by a magnifier, and two marks (*a, a,* fig. 23) made with ink to mark the direction in which the lines on the scales happen to lie most commodiously for resolution, *which will be when the said marks are at right angles to the lines:* then the disc is placed in its recipient (*a,* fig. 8,) and by means of the milling *(b)* it is turned round till the said marks come *into a line with the body,* when it will be in a situation most suited for development: of this I shall speak more at large hereafter.

If the subject is opaque, the disc is made merely of a bit of ivory hollowed out and blackened, to which the object is cemented. When placed in the recipient, the two ink marks *should be at right angles to the body,* and should cross the lines to be resolved at right angles also. The illumination will then come with most effect in the direction of the said marks, or from the side of the stage on which the illuminator (fig. 5) is placed, as it ought to do.

Fig. 9 is a piece of apparatus made to fix on to the body of the Engiscope, in lieu of the metals and object-glasses, to carry single lenses or doublets, when it becomes an excellent microscope.

Fig. 10 is the plan of a four-pillar circular slider-holder with double plates, and a good stiff spring. A segment *(a, a,)* must be cut from the plates on that side next the bar when *in sitû,* otherwise they will come in contact with the neck of the body when the superior plate of the stage is made to traverse in that direction; *b* is an object-holder having a bit of sprung tube in the middle to carry discs, like fig. 8, which are to be fixed into it on the same principle. Charles the XIIth. of Sweden, may it please your worships and reverences, always spread his bread and butter with his thumb; many Asiatics prefer their claws and digits to knives and forks; and I am

very fond of using my fingers to move an object about, instead of traversing screws, *provided the spring of the slider-holder does not permit them to move too easily.* It will be observed that a slider-holder, fashioned like that in the figure, is capable of much latitude of motion in a slider-holder even of moderate size*.

Fig. 11 is a view of a metal of 3-10ths of an inch aperture, and 3-10ths of an inch focus, *of its natural size*: it will serve also to represent any other metal of 3-10ths aperture made on the same plan, to avoid increasing the size of the diagonal metal along with the angle of aperture, and thereby obliterating the effect of the best part of the elliptic speculum. *e* is the lappet to cover up the part of the tube from dust, &c. which is cut away at *f*, in order to admit the approach of a slider-holder to the focus, which lies within the tube: the diagonal is shewn in dotted lines. Fig. 12 is the trough slider-holder, an indispensable appendage to a pair of metals constructed in this way: it is of the four-pillar model, but its superior plate is bent hollow to adapt itself to the tube containing the metals; it is also blackened and perforated. The slider-holder, which must be very small, very thin, and likewise blackened, is seen *in sitû* at *a*. Beneath the trough may be seen a pair of plates, between which is passed the slide of diaphragms (fig. 13), for improving the vision of certain objects not contained by sliders, having very small holes in them, which of course supersede its use. The said diaphragms applied immediately behind objects seen by the other metals, are of little use, and do not answer so well as those in the slide placed under the stage. The three figures, included by the bracket, are of the full size.

Fig 14. is the piece which carries the slide of diaphragms

* I have sometimes thought a very good and simple slider-holder might be made of a circular magnet, or two semicircular ones slightly separated, or even of two bars with the help of a steel slider-holder like that at *b*, which would always cling to the magnet in any position, and still allow of being moved about.

(fig. 15.); it has a groove in it which greatly resembles that part of the old compound microscopes which used to carry the slide of object-glasses, and has, like it, an internal spring, which catches in the notches of the slide, when each hole becomes concentric with the aperture in the tube of reflectors. This part, however, of the apparatus is not essential. I myself prefer a slide of diaphragms to a wheel, because it is evident that a wheel can only give an eccentric pencil for lined objects in *two directions*, as the wheel moves backwards and forwards; whereas a slide does in *any direction*, except in the line of the body, because the catches which fasten it to the under plate of the stage are placed in that direction. This faculty of giving an eccentric pencil, or, what is the same thing, an oblique light, in almost any direction, will be found of great use in resolving test objects by *daylight*,—with artificial light, diaphragms are of but little service. Where the diaphragms and the body are both fixtures, of course no oblique illumination can be had, unless, indeed, a fixed arrangement is made to that effect, and then of course a direct light cannot be obtained : on this account, sliding tubes below the stage, affixed to its immoveable under plate, are inadmissible in the kind of instrument under consideration.

Fig. 15 is the slide belonging to the groove: it has four holes in it, the largest half an inch in diameter, as may be seen by reference to the scale. It would have been better to have been full three-quarters, and the rest in proportion. The aperture in the under plate of the stage should be a full inch, or even more, lest it should, under any circumstances, operate on the visual pencil, or the edges of the field of view.

Fig. 16 is a glass tank, chiefly intended for holding aquatic plants. The back and sides are composed of thick plate glass, to which a very thin piece is attached in front, the whole being cemented and firmly bound together, both at top and bottom, with a slip of brass. A piece of plate glass is introduced at pleasure, to press that part of the plant to be examined against

the front of the glass trough. This tank is fixed to the superior plate of the stage by a peg to be screwed to it at pleasure, somewhat after the way in which a salt box is to a wall. This piece of apparatus is much superior to a phial or flattened tube.

Fig. 17 is a *clasp* of diaphragms to be applied to the tube of reflectors itself: *it is seen flattened,* and not curved, as it should be, like that belonging to the silver cup (fig. 3), to cling to the tube. I have already observed that we are unable to apply a shallow eye-glass, or to obtain a large field of view with the Amician Engiscope, unless the aperture in the side of the tube admitting light from the object is opened out considerably more than will consist with distinctness when deeper eye-glasses are employed, which take in but a very small portion of an object, and therefore will do very well wieh a smaller hole, without having the edges of their field encroached upon thereby.

By means of this contrivance the hole in the tube of reflectors may be made as large as is necessary for the low powers, and again contracted for the high ones, without, as it seems to me, diminishing the quantity of light, when *transparent objects are viewed;* though with opaque ones the case is very different. *d* is the fragment of a tube of reflectors; *c, c,* the direction of the circular line passing through the centre of the hole in the side; *a, a,* a longitudinal line passing also through the centre of the hole; *b, b,* a line passing through the centre of the three holes in the clasp made to coincide with the circular line on the tube *(c, c).* In like manner any of the three lines passing through the three holes may be made to correspond with the longitudinal line on the tube, and when the lines in both are adjusted, of course the holes in the clasp of diaphragms must be concentric with that in the side of the tube. The holes, when high powers are used, may be as small as those made by a large pin, or a little larger than the space taken in by the field.

These diaphragms may also be adjusted by putting on the lowest eye-piece, and causing the spot of light which will be

seen in the field to become centrical, moving the diaphragm about till this is effected. It will be observed that fig. 16 is of the full size for a metal of 3-10ths of an inch aperture.

All the figures described are one-third of the natural size, except where the contrary is stated.

There is a variety of apparatus *common to this and other engiscopes,* such as fish-pans, aquatic and dry live-boxes, tubes, slides for crystallizations, diagonal and polarizing eye-tubes, micrometers, apparatus for viewing the circulation of the blood in animals, and the cyclosis in plants, &c. &c. which the reader will find fully described in the "Microscopic Illustrations," "Microscopic Cabinet," "Treatise on Animalcules," "List of Microscopic Objects," &c. I have, I think, described every thing *peculiar* and *indispensable* to the instrument under consideration. I may observe, that though the instrument is represented in perspective (which will not in strictness consist with a regular scale), yet many parts of the drawing supposed to be *nearly in the point of sight, and not foreshortened,* are made to correspond with the scale, and to shew their true dimensions according to it. Thus the superior plate of the stage cannot have its parts measured by the scale, but its lateral view may ; the diameter of the mirror may be obtained, the size of the body, pillar and stand, &c. &c.

I do not know of any *improvements* which can now be made in the instrument, unless perchance that the mirror might be made like that in fig. 1 in the "Microscopic Illustrations," but this is not very material.

I will, however, venture to suggest one thing, though I am afraid it will be thought rather fanciful.

It would not be amiss if the concave metals, and the piece to which they are soldered, were perforated like those of the Gregorian telescope, as a lens of the same focus as the acting one of the concave metal might be set in the hole, which might act as a *finder* to the Engiscope itself: indeed, a light small body, with a single eye-glass having cross hairs in its focus,

so adjusted that their intersection should always take place on an object placed in the centre of the field of view of the Engiscope, might also be applied, and have its focus adjusted to suit the primary instrument, by means of setting the object-glass in a tube sliding on that containing the metals. Thus two persons might view the object under consideration at the same time, and one manage for the other, at least while the instrument was in the position shown in fig. 1, in which, however, all its capabilities may be developed: this at all events would strongly remind us of the two kings of Brentford smelling at one nosegay.

THE VARIOUS METHODS OF OBSERVING WITH THE AMICIAN CATADIOPTRIC ENGISCOPE AND HORIZONTAL ACHROMATICS*, MADE EASY AND SIMPLE AT LAST.

General Observations.

As horizontal achromatics must have their stands, mountings, and apparatus, constructed very nearly in the same manner as the Amician reflectors,—the same sauce which does for the

* First introduced into use by Professor Amici, of Modena: they possess in particular the property of giving an *erect image*, when used with a diagonal metal or plate of glass applied to their visual pencils for the purpose of causing their image to be seen on paper placed underneath, to assist observers who make drawings of microscopic objects, which are thus represented exactly in their natural positions, while they are confined to the stage purely by their own gravitation, which circumstances are frequently a great accommodation to microscopists.

goose shall serve for the gander also, by your leave, ladies and gents., observers with the aforesaid instruments.

I have often wished it was possible to invent some kind of a *veritable* finder for Engiscopes, like those used for telescopes; in the present case such a piece of apparatus would be invaluable, for it would make the management of the instruments I am now treating of as simple as that of any others of the refracting kind; but as I conceive this to be impracticable, it will always involve somewhat of the difficulty (at least with beginners) which is at first experienced in using a Newtonian telescope, viz., we must be content to acquire the habit of pointing the instrument in a direction totally different to that in which we look, and in like manner the Amician reflector and horizontal achromatics *must be managed exactly as if the observer had to look in a line formed by the axis of the illuminating mirror passing through the centre of the stage, instead of at right angles to the same*, as will be seen in the sequel; but before I proceed to business, I must premise a few remarks on the optical part of the instrument.

There have been five and six sets of metals made for the improved Amician Engiscope, as follow:

No.	Solar Focus.	Angle of Aperture.
1	2 Inches.	$13\frac{3}{4}°$
2	1 Do.	$18\frac{1}{3}°$
3	$\frac{6}{10}$	$27\frac{1}{2}°$
4	$\frac{4}{10}$	$36\frac{1}{2}°$
5	$\frac{3}{10}$	$41\frac{1}{4}°$
6	$\frac{3}{10}$	55°

Various eye-glasses operate along with these objective metals,

giving magnifying powers almost *ad libitum*, which may again be considerably increased by drawing out the inner tube into which they slide : thus every degree of power may be obtained between that given by a lens of half an inch focus, and one of only 1-60th of an inch. Each eye-piece should have engraved upon it, by the maker, the power it gives with each of the sets of metals, *the body being contracted to its minimum length.* Each set of metals should also have engraved upon its outer tube the focus of the concave metal and its angle of aperture, for there is frequently but little difference in their outward appearance, save that one seems *a little longer than the other:* this circumstance has frequently given interested persons an opportunity of using a metal with a small angle of aperture instead of a large one; and thus the character of the instrument has been injured in the opinion of simple confiding people.

It will be observed that *no attempt is made to give the metals of long focus a large angle of aperture,* as might have been done*. The reason of this is, that it is a point of the utmost importance to gain space between the object and the side of the tube which contains the reflectors for the illumination of opaque objects; accordingly, No. 1 gives half an inch for this purpose, No. 2 one-fifth, No. 3 one-tenth, No. 4 one-twentieth, No. 5 scarcely any space, and No. 6 cannot be used for opaque objects at all, except by removing the diagonal metal, and simply placing an object in its focus : it is especially devoted to the most difficult class of transparent test objects.

* Since diminishing the focus of these metals adds so greatly to the difficulty of working them, especially if the angle of aperture is considerable, it may be worth while, *under existing circumstances,* to try what can be done by giving the metals of long focus a large angle of aperture. The oblique lines on the scales of the brassica have been seen, though faintly, with a metal of so long a focus as an inch and a half with an inch of aperture, having a very exact figure. This aperture is certainly not sufficient to shew them perfectly ; it should be equal to the focus. All the common lined tests may be seen very well with a one inch focus metal, with half an inch of aperture.

Nos. 1, 2, and 3, are those metals most useful for examining opaque objects: No. 3 is also a capital working metal for all sorts of transparent objects; indeed, there are not above four or five objects known that it will not exhibit.

The microscopes and engiscopes produced by myself and Mr. Pritchard, *are constructed* on the *same principles, as far as possible*; they must, therefore, be used and managed nearly in the same way: consequently the various cautions and directions given in the "Microscopic Illustrations" for managing the *Operative Aplanatic Engiscope*, and in the "Microscopic Cabinet" for dealing with the *Jewel and Doublet Microscopes*, must not be overlooked as altogether irrelevant and inapplicable to the instruments now under consideration; for, in fact, the only peculiarity in the Amician Engiscopes and horizontal Achromatics is, that their bodies are *a fixture, and motions are given to their stages.*

I should strongly advise you never to attempt to wipe or clean the metals yourself: you may clean the prism (fig. 2) I have spoken of, if necessary, with a bit of chamois or wash-leather perfectly free from dust, and whiting, and a little very strong spirits of wine: the same material also serves for wiping the metals, if it must be done by yourself, but recollect it will be a singular piece of good fortune if after having cleaned them you should be able to return them into their containing tubes so as to be in perfect adjustment. Many half-taught people fancy that the metals of the Amician are out of adjustment when they are in, and in when they are out, because they are not aware that the plane or diagonal metal, *being only of the exact size wanted, and every atom of it actually operating up to its extreme edges, is never precisely concentric with the concave.* A section of a cone, at an angle of forty-five degrees, will shew and verify this fact (vide also fig. 28): the same circumstance holds good with the Newtonian telescope, only this instrument having a very small angle of aperture, and a small diagonal metal, *the edges of which are never in use,* permits us to place

the said diagonal in a truly centrical position. The adjustment of the metals of the Amician with each other may be judged of according to the rules laid down in the "Microscopic Cabinet," p. 209.

I once saw a rich fellow, who passed for a man of science, (by virtue of buying scientific books and instruments, and giving good dinners to persons who really were entitled to that appellation) deliberately take out the metals of a Gregorian telescope and deliver them to his butler to clean, observing, that he expected a party of friends to examine some double stars with the instrument in the evening! Emboldened by his sublime example, as individuals are frequently placed in situations where the assistance of an optician cannot be had, I shall here give the method of taking out and cleaning the metals :—First, make a mark on the head at the end of the tube of reflectors corresponding to another on the tube itself,—this is done to enable you to return the concave back precisely into the place it should occupy after you have cleaned it:—then, with a strong pair of pliers or hand-vice, *twist* the metal out by forcibly grasping the projecting bit of brass at the extremity, and turning it round; *the plane metal can then be got at so easily that it will hardly be necessary to remove it*: then wipe both metals with the leather moistened with the strongest alcohol, and afterwards with another piece of dry leather. If any dust has collected on their surface, which may be expected to scratch them, remove it with a camel's hair pencil before you apply the leather, or wipe them very gently at first. There is frequently a brown tarnish formed on metals of a certain age, which cannot be removed by this process: in this case it will be requisite to apply a saturated solution of citric acid in distilled water to them for *an instant*, licking it off with the tongue, and then washing the speculum thoroughly with alcohol. As the citric sold is often adulterated with sulphuric and other acids, (which would be destructive to the polish) it will perhaps be safer to use *boiled lemon juice*.

If, however, they have lost their polish, and become grey and oxidated, you may, if you are a bold man, with a mechanical turn, attempt to repolish, (one of the most delicate operations the imagination can conceive); that is to say, if the metal has become useless, and *you therefore cannot alter it for the worse*, otherwise you had better let it alone; for if you should succeed in repolishing it, it is ten to one but that *the figure will be utterly ruined.* Procure then a piece of very thin chamois or white kid-skin leather, of an equal thickness throughout; melt some bees'-wax, and having first stretched the leather into a concave figure over one of your fingers, put some of the wax, when nearly cold, into it, and apply it to the metal, stretching the leather well, and pressing it hard, so that it may take an exact impression of its figure: when the wax is quite hard, trim off the edges of the leather with a pair of scissors, leaving its convex surface of the same size as the metal to be polished. Then rub this tool over with some of the finest-washed crocus powder, and rub the loose particles off with a clean brush or piece of leather. Make your tool fast to something or another, taking great care not to injure its figure, and lay the metal on it, working it steadily backwards and forwards *across and across*, but never circularly, and using the least pressure possible; have patience, and the polish will gradually return; try the figure from time to time, according to the rules laid down in the "Microscopic Cabinet," p. 199, and do not attempt to get a perfect polish; *be content with one which is sufficient for practical purposes.* The figure of the metal will probably become too spherical with the cross motions: if you find this to be the case, you may give it *a few circular strokes*, but be very cautious, or it will in this way become too flat at the edges, *i. e.* parabolical or hyperbolical*, which is a much worse

* The whole secret of figuring metals (an operation effected in the process of polishing) seems to reside in the knowledge that a movement across and across in a right line given to the metal, (whether the tool

fault than too spherical. The metals are polished originally on a pitch stool, which you may use if you like instead of a leather one; but unless you have some practice, you will probably have the best chance of retaining the original figure of the metal with the leather and wax*.

The plane metal is taken out by unscrewing the adjusting screw: at its back marks must be made, as before directed, to enable you to screw it on again in adjustment: and now I am sorry to say, the figure of this is still more ticklish than that of the others; I am afraid it is scarcely possible for an ordinary person to do any thing with it. You may, if you please, make the following experiment:—

Get three pieces of brass *planed* perfectly flat, place a little of the finest-washed crocus powder, or putty mixed with water,

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which forms it is stationary or revolving in a lathe,) gives a spherical figure, and that this figure can be converted, first into an ellipsis, then into a parabola, and finally into a hyperbola, or ultra-hyperbola, by merely changing the cross motion into a circular one, and cutting it short at the requisite point. A perfectly plane or flat figure seems to be of still more difficult attainment than any concave or convex one: it is procured by working *three* metallic surfaces successively against each other; two only worked together are sure to become concave and convex respectively, but of the same radius. When metals are of long focus and small angular aperture (as is the case in telescopes), the great difficulty seems to be in keeping their figures sufficiently near the sphere, at least in the operation of polishing: nearly all the reflecting telescopes I ever saw incline to be too hyperbolic (I mean too flat at the edges) in figure; but it is quite possible to hit off the figure of an ellipse (which is that of the metal of an engiscope), perfectly true, even with a true *black polish.*

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* A critique on the merits and defects of the Amician Engiscope has just appeared in Napier's "Encyclopædia Britannica," art. Microscope, part 84, p. 43, col. 2.—*A. P.*

between two of them, and work them together till smooth, and also work these two alternately with the third piece, so that the three being ground together may always preserve their flat surface, as they will do; they will imbibe enough of the polishing powder, even after they are wiped perfectly clean, to polish a plane metal indifferently well, which is drawn *in one direction* over any one of these charged surfaces, and if *this* operation is carefully done, the figure will be preserved*.

I dare say every regular optician will laugh heartily at these directions; but until their worships and reverences will please to learn to work these small metals, we must endeavour to preserve those already in existence†, the best way we can. I

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* The plane metals are originally formed in the following manner:— About half a dozen of the small pieces of brass which carry the screws, by which the diagonal metals are retained in their places, are soldered to a plate of a very thin speculum metal, about an inch in diameter, (the thickness used may be rendered evident by abrading the edge of one with a file); this plate is then figured as a single plane metal, just as those of Newtonian telescopes are; when polished, it is cut or broke into pieces, each having the bit of brass at its back, and the edges of such as turn out good and true are carefully ground down to the required size: the arms which carry them are carefully cut out of a disc of brass, soldered to a piece of very thin tube, and then inserted *in sitû*. The adjustment of the plane metal is performed by a single screw connecting the arm and the metal together, and here the skill of the workman is shown, and put to the test, in the nice manner in which he must adapt the two little plane surfaces to each other, having to perform in this way what is, in the Newtonian and other telescopes, effected by the joint action of three screws. Little do observers know of the mass of work there is in a pair of these delicate metals duly figured and adjusted.

† I conceive that even where an artist possesses the necessary capacity, and has learnt the principle and method of working metals of *very large aperture*, the practice of nearly a lifetime will be requisite to attain the

have merely recommended such means of keeping the specula in order as I think most likely to succeed with *amateurs and observers* in general. No man knows better than I do how very small an error in a reflecting surface is sufficient to create confusion in an image, especially in metals worked on so very small a scale: I dare say a millionth part of an inch of error or inequality at the edges of their curves, that is to say, being too flat at their margins, or too deep in their centres, by some such quantity, will be quite sufficient to render the performance of a metal very bad.

I forgot to mention, in its proper place, that a small sable's-hair pencil warmed at the fire, (which may be easily introduced into the tube of reflectors, without disturbing the metals,) will suffice for cleaning the specula from any casual particles of dust, &c. which may adhere to them.

I shall now proceed, on the supposition that every thing about the instrument is in good order and condition; that you have selected the metals you mean to use; fixed them on in careful adjustment; drawn back the slide from the lateral hole; screwed on the cruciform stand, and drawn out the slides of the pillar to the proper height*.

FIRST METHOD OF OBSERVATION, WITH THE BODY HORIZONTAL, AND THE BAR DEPENDENT AND VERTICAL.

TRANSPARENT OBJECTS.

Fig. 1 represents the Engiscope set up and prepared for action, in the aforesaid method; and observe, gentle reader,

tact of producing exquisite figures in such specula at pleasure; even if it were otherwise, the production of fresh works of art of the highest merit would not diminish the value of those of the ancient masters, which, though they may be equalled, cannot be surpassed.

* It will probably be found convenient in packing the instrument, to put the cruciform stand into a shallow drawer, at the bottom of the case, by itself; and to retain as much of the apparatus attached to the bar and body *in sitú* as may be, in stowing away the rest of the things.

that here you may set up your staff and proceed no farther, unless you like, for every species of object may be duly observed in this way; neither will it matter whether the bar is a fixture, and supports the body, as in most of the foreign-made instruments, or whether a pillar performs this office, for the mode of procedure will be just the same. Now mind what I say: this instrument is like the Irishman's crooked gun, which used to shoot round the corner; therefore, the first thing you have to do is to mount your object, just as if you had to look at the dotted eye (*r*) in the line of the dotted arrow (*q p*), and as if the hole in the tube of reflectors was a magnifier: recollect the distance of the focus of the pair of metals you are using from the side of the tube, and observe that there is a line drawn round the said tube, passing through the hole by way of a rough guide for you to place the object in its proper situation. The second thing you have to do is to direct the light by means of the mirror (*k*), also just as if you had to look at *r*, in the line *p q*, instead of round the corner at *e*. The third thing you have to do is to adjust the focus, just as if you had to look at *k*, in the line *p q*, instead of round the corner at *e*, by means of the screw (*i*), first screwing up the milled head of the pinching screw (*h*); till this is done the said screw (*i*) does not act, though the stage will move at pleasure up and down the bar.

Notwithstanding the explanation given of the use of the various apparatus belonging to the instrument, in the preceding pages, as a *da capo* is often necessary to produce a decisive effect on the mind of the reader, I shall observe that all the nicknacks used for the examination of transparent objects apply to this instrument very nearly in the same way as to any other, according to the humour of the observer. Thus, if your objects are contained in sliders, you put on the slider-holder, (fig. 10), and turn it one quarter round to fix it to the stage, and you may either use the double screws (*m*), to call into action the traversing plates, or move the slider-

holder about with your fingers, which were made before traversing screws were invented; and if the object does not yield too easily to the touch, and your elbows are rested in some way together with your wrists, you will, I think, find little use for artificial movements, unless your hand trembles.

If the nature of the object to be examined allows of its being laid on a disc of glass, then use the raised stage, (fig. 6); you may remove its arm (*a*), if you find it in the way, and lay the glass on the rim thereof, and proceed as before: recollect, whenever you use daylight, not to employ the concave mirror, (if there is one) but the plane one; also affix on the slide of diaphragms (15) to the under plate of the stage: be sure you turn it round to fix it, or it will tumble down and break your mirror; try the various holes, to ascertain which best regulates the light, and tempers it to the shade best adapted for exhibiting your object well: recollect that oblique light is rarely required, except for proof-lined objects; therefore keep the diaphragm concentric with the hole in the tube of reflectors, and then you have direct light. Of course, if you have living aquatic objects or animalcules to observe, you use an aquatic live-box; if crystallizations of salts, a slide proper for them, &c. &c.

If you use artificial light your lamp or candle must have a bull's-eye lens or condenser applied to it, to render its rays parallel; every thing then goes on as usual, except that, in my opinion, the diaphragms will do no good with artificial light, which can always be obtained of the precise degree of intensity required by removing it to a proper distance from the instrument.

A lamp fed with oxygen gas introduced into the wick, such as has been frequently used of late years by exhibitors of objects with *pretended* oxy-hydrogen microscopes, would be an admirable addition to an Amician Engiscope, both for the purpose of obliterating the brownish tint given to objects by all reflectors,

when their powers are high, and of rendering its light equal to that possessed by refractors under ordinary circumstances.

If the tube carrying the object-glasses is used instead of the metals, the raised stage will not be needed; but the other arrangements will not be disturbed.

Touching transparent lined objects, I beg you to study the cautions given relative to their resolution, farther on, particularly as to the method of illuminating them aright. You will easily acquire the method of managing your mirror, so as to get oblique light with it in any direction at pleasure, by having *a piece of rubbed glass* to lay on your stage, *and observing with your naked eye the direction in which the spectrum of a candle or window travels over it as you move your mirror about*; only you must, of course, remove your eye from the instrument for this purpose, which is inconvenient: there are other methods of ascertaining this very essential point, as you will see farther on.

OPAQUE OBJECTS.

If you desire to examine an opaque body requiring shade as well as light to reveal the nature of it, and it be thought most advisable to employ day-light, it may be sufficient, if the day is bright and sunny, and the power employed low, merely to place the instrument, duly equipped with its slider-holder and slide, &c. near a window, in such a position that the body shall be parallel to it; and thus let the light fall upon the object, turning the body, perhaps, a little round in its split socket, so that the end of the bar shall point towards the window, if the tube of reflectors shall appear in any degree to shade it: if it is a subject not contained in a slider, nor placed on a disc or cylinder, but simply mounted on a pin, as, for example, an insect from a common entomological cabinet drawer, the black box (fig. 6) must be used, with its bottom *(e)* fixed on, but without

the little supplementary black velvet disc, grasping the pin by means of the miniature vice *(d)* on the arm *(b)*.

If the use of the condensers (figs. 4 and 5) is requisite to brighten the object, these may be used either separately or combined. The focus of the largest (fig. 5) is about $2\frac{1}{2}$ inches, but should be rather *more* than less than that; accordingly it must be so adjusted in its slide as to be at $2\frac{1}{2}$ inches distant from the object it is to illumine, but still as much nearer than that as may be necessary to cause the image of the window to disappear*; the small one is about an inch focus, (but rather more than less) and is in like manner to be adjusted, so as to be at about an inch from the object.

If, however, the power is high, and the object dark, combine both the condensers as follows :—fix the smaller half an inch distant from the object, and the other large one an inch and three-eighths from the small one ; take care that the axes of both are in a line with the object and the light, and also that the planes of both lenses are parallel to each other. This combination gives a degree of brightness of illumination equal to what would be obtained from a lens of half an inch focus, and an inch of aperture, (if, indeed, it could have such an aperture,) barring the light lost by the two surfaces of the second lens, and might be rendered twice as great by giving an aperture of an inch and a half to the illuminator which first collects the rays, instead of an inch.

When this arrangement is made it will do as well for artificial light as day-light; all that is requisite will be to place a lamp or wax-taper, furnished with a bull's-eye lens to *render its rays parallel*, on the side of the Engiscope on which the illuminators are placed, a little above the level of the stage.

If the object is best illuminated by silver cups, select that which is adapted to the specula you use, and fix it on their

* This gives the maximum of brightness, which always lays within the focus of an uncorrected lens, and prevents the object from being confused by the traits in the spectrum of the window.

containing tube, taking care that both the holes coincide: you must now, if your object has no black ground attached to it, use the little black velvet one (*a*, fig 6), and remove the bottom of the black box (*e*), to allow the light of the illuminator (fig. 7) to reach the cup. The said illuminating lens is to be fixed on the bar between the stage and the plane mirror (*k*), in order to effect which, the mirror must be stripped off, and then put on again in its place, after the lens has been slid on the bar. You now reflect either the light of the sky, or that of your bull's-eye lamp upwards, by means of the plane mirror.

When you are observing with cups, be very sparing in using the traversing motions of the stage: *employ them only for the finishing touch*, after you have done your best to get your object in its place, by moving about the needle (*d*, fig. 6.) I have given my reasons for this already, in the description of the black box and its accessory parts.

The object-glasses, of course, have cups adapted to them, both singly and in combination, by being screwed to their cells. When used, they require the same apparatus to be employed as those made for the metals. I have not given any figures of these, because they are so common that every one is acquainted with them.

The best situation for the illuminating lens will be pretty close under the stage; this, however, will depend a good deal on the length of its focus,—a few experiments will soon teach you its proper locality.

I suppose I need not say that the slide of diaphragms must be taken off by turning it one quarter round, whenever opaque objects are to be shewn by silver cups. I frequently find it necessary to tell my readers *what they are not to do*, as well as what must actually be done.

If the focus of the silver cup you use does not happen to fit the metals well, *owing to its being of too short a focus*, you may make it fit, by drawing out the eye tube, which shortens

the anterior conjugate focus of the metals. The focus of the Amician usually falls a little beyond that of the cups, when the body is contracted to its minimum length*.

A great deal may be done with cups having single lenses inserted in them which they do not fit: by raising or lowering their pouts or settings by means of rings of thin metal, till the focus of the lens and of the cup fall on the same point, the brightness of the object is then very remarkable, even with a lens of 1-60th of an inch focus.

Now if you should not happen to succeed in getting every thing to go on exactly to your mind at first, do not curse the instrument by your gods, and throw your wig behind the fire, and then dance up and down the room like a maniac, as I once saw a Frenchman do; but have a little patience; read my directions over again, weigh well the import of every sentence, and try your luck over again. I am sure, that *so long at least as the instrument is kept in its present position,* its management and that of all its apparatus is so exactly like that of all other microscopes having upright stems, that I think a man pays a small compliment to his understanding in quarrelling with it.

The body, instead of being kept truly horizontal, may be inclined *a little* at the pleasure of the observer, without disturbing any of the arrangements described above.

If at any time during cold weather you should find the steam from your eye continually condensing upon the eye-glass, and thereby impeding your observations, warm the whole instrument at the fire, especially the body and eye-glasses, and you will no longer be annoyed by this inconvenience.

* The method of knowing whether the focus of a silver cup coincides with that of the lens, object glass, or metal attached to it, is this: having illuminated the object in the best way you are able, put it in and out of focus, and see whether the sensible brightness of your field of view is greater either within or without the focus, than at the focal point; if it is, it is a sign that the cup is not properly adjusted; if the light is strongest *within* the focus, the cup or its focus is *not near enough to the object; if beyond the focus, then it is too near.*

SECOND METHOD OF OBSERVATION, BODY INCLINED, BAR POINTING UPWARDS, FOR VIEWING TRANSPARENT OBJECTS BY PURE INTERCEPTED DAY-LIGHT.

This and the following modes of observation, though *not absolutely necessary* to be learnt, are yet highly useful, because they cause the instrument to put forth *its whole mettle*,—they are of course only intended to be studied by graduates of the upper form, who have got over the asses' bridge we have just passed.

Turn the body round in its spring socket till the bar assumes the direction pourtrayed in the miniature skeleton figure marked (19). The mirror must be taken away altogether: the object to be viewed must then be mounted between the bars of the slider-holder as before: the instrument must be placed pretty near the window in this way of using it, that the bar may be so directed that the light of the sky shall fall freely on the object; if oblique light is wanted, turn the body about in its socket till the bar points a little on one side, and tilt the body at the same time till you have attained your object. The slide of diaphragms (fig. 15) will be almost certain to improve the vision of objects seen in this method of mounting, and should therefore be employed, whether the light required is direct or oblique; if the latter is wanted, it must be so placed that the aperture in use shall not be in the axis of the metals, but a little on one side of it, and it will effect this point*. The aforesaid mode of observation is equivalent to that given in the "Microscopic Illustrations," p. 66, for the Explanitic Engiscope. I now proceed to describe what may be con-

* Whenever oblique light is obtained it matters not in what manner: on viewing the visual pencil with a magnifier, it will be found not to present a perfect round disc of light, but one partially illuminated only, the bright portion being always near the margin. Vide "Microscopic Cabinet," p. 172.

sidered merely a modification of the present way of setting up the instrument.

THIRD WAY OF MOUNTING,—BODY HORIZONTAL, BAR VERTICAL, AND ABOVE THE BODY.

Turn the body round in its socket till the bar is truly vertical, and then clamp it tight. The plane mirror must be fixed on the bar as in fig. 18, to reflect the light downwards. This method is extremely useful for observing the crystallization of salts, the bellies and inferior parts of aquatic insects and animalcules, and all sorts of chemical actions. The details are as follow :—

A slip of glass, in a proper brass case, must be warmed, and then inserted between the bars of the slider-holder, to receive the drop of salt to be crystallized, or it may be merely smeared over its surface, so as to present only a very thin film of the fluid, which is perhaps the better way : sometimes the surface of the glass is greasy, and will not take to the salt ; in this case wash it with pure soda, and afterwards polish it a little with a bit of perfectly clean wash-leather impregnated with putty. It must be obvious that this is the best way of viewing crystallizations, for thus the water can pass off freely without steaming the metals or object glasses, and the drop being exposed on a *horizontal surface* will not spread or run about.

As living aquatic insects constantly endeavour to keep in one position, viz. with their bellies undermost, in whatever situation they are placed, this is the best way in which their inferior parts can be viewed ; it is very probable that many animalcules are in a similar predicament*. It is no doubt possible to confine

* The infusoria are always found on the *surface* of the liquids which generate them, probably because air is necessary, not only to their production, but to their existence ; their most natural way of exhibition will therefore be in a *naked* drop of a liquid taken up with the head of a pin, but such a drop will always present a spherical surface on its upper side, which will

an aquatic insect closely in a live-box, and then examine its under parts, but it will be always struggling to regain its natural position, which circumstance will disturb our observations.

Chemical actions, in a small way, will also be best seen in this mode, as any gaseous matter which may escape from the bodies in action can pass off freely, and they are, besides, quite under the control of the experimentalist, who can carry on his operations without removing them from the instrument; a thin watch-glass, having a segment of its middle flattened by being pressed into an appropriate mould while hot, must be fixed into a piece of flat brass of a certain thickness, and capable of being introduced between the bars of the slider-holder, to carry the substance whose actions are to be examined.

FOURTH METHOD OF OBSERVATION,—BODY AND BAR HORIZONTAL, OR SLIGHTLY INCLINED.

This is the best arrangement for viewing transparent objects by artificial light, especially tests, as it allows a taper or lamp to be introduced directly behind the stage, *vide* fig. 20 : it also enables us to use the condensing lens, with a taper, for illuminating opaque objects by means of the silver cups fixed to the tube of reflectors, as already described, *without employing the mirror*, which only renders the operation more complicated, while it occasions a great loss of light. The skeleton figure (20) is a *top view* of the instrument, or an apology for a plan *taken from above*, the eye being supposed to *look down upon it*. The parts will, I think, be easily recognized by merely

operate like a lens, and thus interfere with the action of any instrument employed to view *its superior surface* ; it will also evaporate rapidly unless renewed ; but in the way described, *we look through the under flat surface of the drop*, by which means all the aforesaid inconveniences, together with that resulting from the naked liquid coming in contact with the side of the tube, when metals of very short foci are used, are easily obviated.

considering that the *body has been turned one quarter round in its socket,* carrying the bar along with it.

The light of the taper or lamp* is so very easily managed at the pleasure of the observer, that I should only make the simplest thing in the world difficult and complicated by saying much about it. Of course the nearer it is placed to the stage the stronger and more intense its light will be, and *vice versâ:* if direct rays are required, it must be placed in the axis of the metals directly behind the aperture in the stage ; *if oblique, on one side of it:* vide the dotted figure of the taper. Recollect that the flame must be kept of the exact height of the tube of reflectors: the proper kind of candlestick for the purpose is represented in the "Microscopic Cabinet," p. 245, art. 22.

OPAQUE OBJECTS.

Fig. 21 shows the method of fitting up the instrument in the same position for examining opaque objects with silver cups, in which the same apparatus is used as was described in the first method of observation, except that the plane mirror's services are not in request, the taper or lamp casting its rays immediately on the illuminating lens, which refracts them towards the cup. The lamp, when it has no bull's-eye lens, should be placed at such a distance from the illuminator as is equal to about twice its solar focus: if this is an inch and a half, it will be about 3 inches distant from the said lens ; the brightest part of the flame must be just in the axis. If the needle turns round in its socket, and thereby annoys you, (as it will sometimes do when in the position in which it is represented in the figure,) turn the arm round on the top of the black box till it

* In this case it may be used *without a bull's-eye, or other lens, to make its rays parallel* ; indeed it is frequently most effective in its simple state, especially with proof-lined objects: of this more hereafter.

becomes vertical, and the needle will then remain quiet in any position you may require.

OF THE EXHIBITION OF TEST OBJECTS BY THE AMICIAN REFLECTING ENGISCOPE.

I conceive it to be absolutely necessary that all proof-lined objects, both transparent and opaque, intended for demonstration by the Amician reflector, should be mounted in little circlets of ivory or metal, of which a representation may be seen at fig. 8 (*c*), and also on an enlarged scale at fig. 23. This may cause a little extra trouble and expence, but it will be found well worth while; for I have frequently seen the Amician fail, or perform but indifferently, on tests, not from any lameness or impotency in its optical part, which is second to that of no instrument whatever, but merely because (if I may be allowed the expression) *it could not get at them* properly, so as to be able to exert its full power. This is owing to the impracticability of turning a slider fairly round, when mounted for inspection, on account of its proximity to the side of the tube of reflectors, which is sure to cause it to come in contact with the neck of the body; no such inconvenience, however, will occur when the object-glasses are employed, because their focus will be sufficiently distant from the side of the tube to allow the slider to turn round till it comes into its best position for permitting the object to be illuminated in the most effectual manner.

Fig. 8 is a piece of turned work to be applied to the stage, like the other pieces already described, for carrying the said circlets, the milling at *b* being intended to be turned round until the two ink marks (*a a*), fig. 23, shall come *into a line with the body if the object is transparent*, or *at right angles to it if it is opaque;* the two marks having been previously made in such a manner that an imaginary line drawn through them shall pass at right angles across the particular lines to be demon-

strated: all that is necessary then will be, if the test is a diaphonous one, to use the instrument in the fourth way of mounting, *vide* fig. 20, to keep the system of lines to be resolved perfectly vertical, and to place the taper in the position indicated by the dotted figure of it. All this I think a mere child might be able to do.

If the object is opaque, the instrument will operate best in the first way of mounting (fig. 1*), and the ink marks being placed at right angles to the body will be ready to receive the illumination from the side of the stage in their most favourable attitude for exhibition.

If the object-glasses are used, the same system must be acted upon, though, as I have already said, sliders in this case may be employed: a couple of ink marks are to be made on their sides, as before recommended, that the observer may always know at a glance how they are to be placed.

Fig. 22 represents an enlarged view of the metals of an Amician Engiscope, seen by taking out the eye-piece, after the instrument has been adjusted in the best manner for showing a transparent test; the space occupied by the small metal being dotted, as well as the image of the taper, in order to allow of an imaginary representation of the object, (*a*) with its penumbra (*b*), as seen when the eye-piece is on, that the relative positions of the lines and the flame of the taper may be compared. I have done this for the purpose of showing the reader a circumstance I think I have constantly observed:—First, that the long pyramidal flame of a wax taper acts more favourably on lines than any lamp with a round flame can; and, secondly, that the *wick of the said taper must be parallel to the lines to be brought out.* If the illumination is managed in the opposite way, (*vide* fig. 24,) where the wick of the taper is (by taking out the eye-piece)

* It will frequently be found advantageous to employ a *single* eye-glass, on account of its superior light, in viewing opaque objects, especially if they are tests, and the power is high.

seen in a position either above or below the lines, and at right angles to them, though the lines may certainly be shown in this manner, yet, in my opinion, they are never resolved in that satisfactory manner which leaves us nothing to wish for or desire. If a lamp is employed instead of a taper (which it should not be, for transparent tests), it is of small moment how it is made to act.

When metals are employed, having their sides cut away, and where it is in consequence utterly impossible to turn the slider round, or to employ circlets, (*vide* fig. 11 and 12), showing the slider in its holder, we must be content to illuminate *any how we can;* and a lamp in this case is most likely to operate best.

In Art. 10, line 1, p. 180, of the "Microscopic Cabinet," I have described a method of knowing when the light of an engiscope or microscope is oblique, and when it is direct, together with the mode of ascertaining the direction in which the obliquity takes place; viz. *by putting the object out of focus, and observing whether its penumbra is stationary or not, and if not, in what direction it travels.* Moreover, in Art. 9, I have endeavoured to show how and in what manner the light must be made to traverse the system of lines to be resolved, in order to bring them out to the most advantage. Now by the help of attending to these rules, we may always, even if we have not the power of shifting the direction in which a test lies, cause the light to fall upon it in the best way practicable; for by using a lamp possessing a motion up and down on its stem, as well as from side to side, we can, by a combination of these motions, cause its rays to flash across our object in any direction we please, and this direction, as I have already said, may always be ascertained by putting the object out of focus; and *if we find that its penumbra, or double image, laps over it, and passes backwards and forwards at right angles to the system of lines to be*

exhibited, it is a sign that the illumination is right, (*vide* fig. 22 *b*): if it does not, we must shift the lamp from right to left, or up and down, till our point is attained. Again, this method may be confirmed *by examining the visual pencil; a line drawn from the centre of which towards the middle of the illuminated portion of it at the margin* also lets us know what direction the light is taking, as I have already remarked. If, instead of artificial light, any modification of daylight is used, the same precautions must be taken, and the light made to suit itself to the object, since the object cannot adapt itself to it. I need scarcely say that illuminating mirrors, having a double motion, give oblique light in any direction at the pleasure of the observer.

After all, it is possible, by giving ourselves a little trouble, to fit up sliders, in such a manner that some of the favourable specimens of scales and feathers shall have their *lines parallel to the sides of the slider*; for when this point is gained, the lines will be in their best possible position for resolution, and the full power of the metals can be exerted. The penetrating and defining power of metals, accurately figured, seems so much greater than that of any thing made of glass, notwithstanding the superior light of the latter, that it is in my mind worth any pains which can be bestowed on fitting up a slider, to give the specula an opportunity of doing their utmost, as we know not what discoveries may be missed by presenting an object to them in an unfair and improper manner.

One more caution, and I have done. Whenever the tubes of reflectors, having the largest angular apertures, are used, it is of the utmost consequence that *the object should be placed exactly in the centre of the field of view*, for the error of the oblique pencils continually increases with the extension of the angle of aperture, and causes the vision to be bad at the edges of the field, however perfect the figures of the metals may be. In fact, under such circumstances, the artist can

only work to a point, and there is scarcely more than room for one scale or feather in the perfect part of the field.

If you are desirous of using simple or compound magnifiers, the piece (fig. 9) slips into the neck of the body, and will carry them for you; the instrument then becomes an excellent and very effective microscope, and *the body* of the reflector *a capital handle* to twist it about any how you like.

You now may observe in the four modes, precisely as if you were using the reflectors, or the horizontal objectives, only you have not the trouble of *looking round the corner*; indeed, a course of observations with mere magnifiers would be an excellent preparatory step to using the engiscopic part of the instrument, for it cannot fail to make the student perfectly acquainted with all the capabilities of his instrument *à priori*, so that the management of it, when converted into an engiscope, will become mere child's play to him.

I have neglected to describe in their proper places, figs. 26, 27, and 29. Fig. 26 is a reflecting engiscope of its full size, recommended by the late Charles Tulley, of Islington, and executed by his son William Tulley, whose untimely death every lover of the microscope must deplore. It is an elliptic metal, perforated at the back like that of a Gregorian telescope, in order to allow the rays of a taper, rendered parallel by a lens, or simple daylight, to fall on an opaque object placed in its focus. This is the only kind of engiscope or microscope which will allow an opaque object to be illumined by light *absolutely direct and parallel to its axis*; and the effect of it is singular enough upon some objects: thus, a piece of dial plate enamelled black, upon which by no other instrument could any scratches or markings be seen, instantly appeared of a brownish instead of a black colour, and scratched all over.

I expected that this property would render it a very powerful

agent on opaque-lined objects; this, however, was not the case, for it scarcely shewed them at all; indeed, as the reader well knows, they require oblique, not direct light: doubtless it may reveal things not to be seen by other instruments, and requires to be fully tried.

Fig. 27 is a modification of the Amician Engiscope also originally executed by the late William Tulley. The plane diagonal *(a)* is drawn back and diminished in size, in order that it may operate as an illuminator for a transparent object placed at *c*. This, as to principle, forms the best reflecting engiscope in existence for transparent objects, and has been carried to its utmost limit of perfectibility by Mr. Pott; the difficulty of applying objects to it is, however, so great, that it will never, I think, come into use. The same may be said of 25 and 29.

Fig. 29 is a Catadioptric Engiscope, *invented* by Mr. W. Tulley: it consists of an elliptic metal (*a*), acting with a plane oval one (*b*) placed diagonally, and perforated not far from its centre by a small hole near which the object (*d*) is placed. The rays proceed from the object upwards to the elliptic metal, and are reverberated back from it to the plane one; from thence, at right angles, to the eye-piece. This instrument performs, as well as the Amician, either on transparent or opaque objects, but is not so convenient, neither can it be made on so small a scale or of so short a focus*; the object, however, not being within the tube, is much more easily managed than in any of the others, always excepting that of Professor Amici.

I described these instruments shortly after they were executed, in a paragraph in the Scientific Intelligence of the Quarterly Journal of the Royal Institution.—C. R. G.

* The plane perforated metal might perhaps be made with advantage of *steel*, as it requires to be made *very thin, to give room for placing the object*, (though steel certainly does not reflect so much light as speculum metal); for it is very difficult and hazardous to make the said plane so thin as it requires to be of the latter substance.

CHAP. II.

ON MICROMETERS,

AND THEIR USE IN DETERMINING THE FOCI AND POWER OF OBJECT-GLASSES, METALS, SINGLE AND COMPOUND MAGNIFIERS,

&c. &c.

THE celebrated Mr. Coventry and the late Sir J. Barton greatly distinguished themselves by their delicate Micrometers, divided on metal, ivory, horn, mother-of-pearl, and glass, frequently to the extent of 10,000 divisions to the inch: the artists of the present day find great difficulty in rivalling their exquisite workmanship. We have, however, micrometers very exactly executed to a sufficient degree of fineness for real use; and others formed by delicate screws acting on cobwebs, fine fibres of silk, hair, &c., with which quantities far less than the 10,000th part of an inch can be measured in the most easy and comfortable manner, so as to leave little to be desired in this respect.

It here behoves me to take notice of a remarkable property possessed by grooved surfaces, such as those of micrometers, first noticed, I believe, by Frauenhofer. When we look at the image of a candle, reflected by a grooved surface in the line of its divisions or grooves, we see first a white image of the candle, and on each side of it a number of prismatic images thereof gradually diminishing in strength and intensity, as they recede from the primary image: by turning the micrometer round, they will revolve till they all come to be at right

angles to their original position, which was in a line at right angles to the divisions. These images are generated by what is called INTERFERENCE; and it has been duly ascertained that *their distance from each other is always proportioned to the distance of the divisions of the micrometer, each from each,* cæteris paribus: thus, if there are two sets of divisions on the same micrometer, (say of 500 and 1000 parts to an inch,) the prismatic images will be separated twice as far by the 1000 divisions to an inch, as they are by the other of 500. When we compare two sets of divisions in this manner, we must take care that they are on the same plane, and that the light is reflected by both at the same angle, otherwise a calculation will be requisite to obtain the real value of the divisions, as indicated by the distance of the prismatic images from each other. Now, as the finer the divisions of a micrometer are made, the more the images are separated, this affords an excellent test of the goodness of micrometers, which are often very carelessly divided, and one easily applied—at least to such as are executed on opaque substances. The coloured images may be seen on glass as well as on metal, &c.; but the double images produced by the two surfaces create so much confusion that it is not safe to place much reliance on observations made with them.

Under certain circumstances very accurate measurements of natural grooved surfaces may be executed by means of *interference,* which, indeed, could hardly be done by any other means. Thus Sir D. Brewster traced and measured in this way the lines or grooves on the laminæ which compose the crystalline lenses in the eyes of animals, to their extreme point of convergency at the poles of the lenses, where "*they could not be rendered visible by the best microscope.*" I cannot too strongly recommend to the *real connoisseur* the whole of Sir D.'s paper, "*On the Anatomical and Optical Structure of the Crystalline Lenses of Animals, particularly that of the Cod.*"

in the Phil. Mag. for March 1836, p. 193, as a model both of anatomical and optical investigation executed with the microscope. The whole tribe of lined tests *shew iris tints,* especially by transmitted light; it is therefore probable that they are all grooved, though there is an inexplicable mystery about them, for if their lines are in reality produced on the same principle as those of micrometers, why are they not as easily seen?

No penetrating power, or large angular aperture, is requisite to bring out the lines on a micrometer, though divided nearly as finely as ordinary tests, to the extent, perhaps, of 10,000 divisions in an inch; (the Morpho-Menelaüs has only 12,000 to an inch, and many others even less than 10,000.) The minuteness of the feathers and scales of insects is a sufficient reason why we cannot observe the effect of the interference of light upon them, for a certain extent of grooved surface seems a necessary condition for our perceiving the prismatic images of the candle, which became more and more distant from the white one, as the distances between the grooves are lessened, and the scale becomes finer: if the scales were about a quarter of an inch square, instead of their actual minute size, I make no doubt we should be able to measure the interval between their apparent lines by interference, as accurately and readily, or perhaps more so, than by any other means.

Micrometers for engiscopes and telescopes are made much in the same way, and on the same principles; thus we have the divided object-glass micrometer for both, only made on a small scale to suit the engiscope, and, in the case of this instrument, generally by a *divided concave lens* only, placed before the object-glasses or metals, and attached to a sliding scale, with fine divisions, a nonius, &c., by which very minute quantities can be measured: this kind of micrometer is the best for measuring the fineness of wool, hair, silk, cotton,

and the diameters of a variety of similar objects, but cannot easily be applied to engiscopes having objectives of very short focus.

I believe it may be pretty safely asserted, that there is no sort of micrometer for engiscopes superior to those usually made for astronomical telescopes, consisting of moveable cob-webs, working in the field of view, exactly in the focus of the eye-glass, and in the plane of the image; only in the engiscope it will be advisable to apply these to a negative eye-glass, instead of a positive one; at least if the goniometrical part, or that which measures angles as well as distances, is not required*. Thus slits can be cut through the eye-tube and eye-piece of the engiscope, and the apparatus contained in a moveable slide, inserted exactly in the locality of the field-bar, and in this manner made to suit several eye-pieces, which I never suppose to be of such short focus as to preclude this arrangement; when withdrawn, a common field bar may be inserted in lieu of them, or by turning the eye-glass a little round, the slits will be covered by the eye-tube, and light and dust prevented from entering.

As screws are made having a thousand threads to the inch, it is easy to see that such micrometers may easily be made to indicate *very minute quantities indeed*, by dividing the revolution of the screw into a vast number of parts, by means of a divided circle of considerable diameter attached to it; indeed, there is hardly any limit to the exactness which may be

* For the purpose of measuring angles, of course there is nothing superior to the apparatus here mentioned, but it will require a positive eye-piece; in short it must be in all respects similar to that applied to the best astronomical telescopes: there is, however, a very simple method of measuring the angles of microscopic crystals, &c., which is, to attach a camera lucida eye-piece to the body of the microscope when in a horizontal position, and make a drawing on paper of the crystals, or other bodies whose angles we wish to measure, which of course can always be done with a protractor, the legs of the angles being sufficiently produced for the purpose.

obtained in this way, *in principle* at least: unfortunately, however, screws, when much used, contract a degree of looseness which prevents them from causing a movement in the cobwebs the instant they are turned round, especially when moved in an opposite direction to that in which they have previously been worked. This defect may *apparently* be remedied by the action of springs bearing against the screws; but the natural drunkenness or unevenness of the threads of the best screws, and its effect on the accuracy of the results given by the instrument, must for ever remain the same.

I am myself much disposed to doubt whether, if we had micrometers capable of indicating, with the greatest accuracy, the millionth part of an inch, we could with certainty measure such a quantity with them. I have frequently tried to measure a smaller quantity than the 40 or 50,000th part of an inch with an engiscope having an objective of 2-10ths of an inch focus, and a deep eye-glass, used with one of Troughton's best micrometers, *which, under the circumstances, indicated quantities far less,* but I do not think that any reliance could be placed on measurements of smaller quantities than those I have mentioned, made with such an instrument: but when we consider that achromatic triplet objectives are now made of not more than 1-18th of an inch focus, perhaps a very strong practised eye might, with their assistance, *when attached to a long body,* measure even so small a quantity as the 1-200,000th part of an inch *with certainty;* but I question if it could proceed much further. The two edges of a cobweb frequently are not parallel to each other, which is apt to cause a slight inaccuracy in mensuration; a cobweb seems to me not to be a round, but rather a flattish thread, so that if it becomes at all *twisted,* it must, like a piece of tape, present different apparent widths in different places; moreover, as substances of animal origin, they are subject to decomposition, from the action of air and moisture upon them. To remedy these evils, I have proposed*

* *Vide* Quarterly Journal of Science.

to construct artificial cobwebs from a thick solution of caoutchouc in the purest rectified spirits of turpentine or naphtha: this substance (Indian rubber) being, it is well known, very little affected by the action of either air or water, extremely strong and elastic, and capable of being drawn out into threads of any degree of fineness, when dissolved as aforesaid: and if the operation is carried on from a homogeneous solution of the Indian rubber, perfectly round and parallel threads may be obtained. These will stretch to double their length without snapping, are as opaque as the web of the spider, and, like it, resist the action of the solar rays, when condensed by an object-glass.

When measurements of opaque bodies are to be executed with an engiscope, or of certain transparent ones, when the power is high, the field of view is apt to grow too dark to allow us to see either cobwebs or divisions sufficiently well; in these dilemmas a little accession of light may become very acceptable, and can be obtained by inserting a diagonal stop or field-bar, gilt but unpolished, into the body of the engiscope, between the field and object-glass, a hole being made in the side of the body to permit the light of a lanthorn or taper, &c. to be reflected towards the micrometer (as in astronomical instruments in a similar predicament), by the said gilt diagonal stop.

As to other species of micrometers, there are, perhaps, none superior to those executed on thin slips of mother-of-pearl, provided they are made with long divisions at every ten, and shorter at every five strokes, something like those on a foot-rule, and are not too broad. I do not much admire micrometers on glass myself, even when the strokes are deep enough to allow black lead to be rubbed into them, to render them visible in a commodious manner; for they do not admit of leading strokes to enable us to count them easily (at least I never saw any executed in this way on glass), and unless we can count the divisions with certainty, they are, I think, of

little use. Mother-of-pearl micrometers, divided into 100 parts in an inch, and from thence to 1000, will be found to give satisfaction in most cases where single or compound magnifiers are employed; and so will divisions on steel, as far as 5 or 10,000 parts to an inch. When a micrometer having only 200 divisions to an inch is inserted into the field-bar of an engiscope, it may easily be made to indicate so small a quantity as the 10,000th of an inch, provided the body is pretty long and the object-glass deep; and if the eye-tube is so constructed as to admit of being thrust in till the total length of the body is shortened to one half, the divisions in the aforesaid micrometer will, in that state, have their value doubled; that is, they will become equal to the 5000th of an inch. Moreover, by having divisions engraved on the eye-tube, and ascertaining their value, we gain the advantage of a variable scale, of every dimension between the 10,000th and 5000th part of an inch, which is a great convenience in measuring microscopic objects. This leads me to that part of the present subject which treats

OF ASCERTAINING THE VALUE OF THE DIVISIONS OF THE SCALE OF MICROMETRICAL EYE-PIECES FOR ENGISCOPES.

I consider it the bounden duty of every optician who sells an engiscope having a micrometer in its field of view, to ascertain the value of its divisions with every object-glass belonging to it; also the alteration made by pulling out the eye-tube to the various divisions marked on it; and if there is more than one eye-piece having a micrometer belonging to it, then the value of the divisions of this also. As, however, it is part of my subject, I shall give a few examples of the way in which this is done, for the benefit of observers.

Example I.

I have a mother-of-pearl micrometer, having 200 divisions

to an inch, in the field-bar of an eye-piece. I wish to know what is the value of them with a particular body and object-glass?

I place a micrometer, having 1000 divisions in an inch*, on the stage, and find that one of its divisions seems just equal to one on the field-bar; the value of which is therefore 1-1000th part of an inch. In order, however, to be quite certain that it is so, I compare ten of the divisions of the one against ten of the other; and now I find that my observation was not quite right, for ten of the divisions of the micrometer on the stage are only equal to nine and a half of those on the eye-piece; so, as fractions are very troublesome things, I just draw out the eye-tube a little, until the two sets of divisions exactly subtend each other, making a mark on the eye-tube for adjustment, when I use the object-glass in executing measurements†.

Example II.

I have a cobweb micrometer also; I wish to know the value of a revolution of its wheel, and the divisions upon it, with the same object-glass, eye-piece, and body, as before: I therefore insert it in the place of the field-bar. Now the screw of the said micrometer is supposed to have a hundred threads to an inch; its wheel also is divided into a hundred parts. On observing a set of divisions on the same stage micrometer used before, I find that five revolutions of the wheel cause the cobwebs to open to somewhat more than ten divisions of the aforesaid micrometer; I therefore push in the eye-tube till the space between the cobwebs is exactly equal to the ten divisions: it is evident now that one revolution of the wheel is equal to 1-500th of an inch, and each of the

* This will be found a very convenient scale for the purpose.

† I presume I need scarcely observe that when the value of the divisions has been determined, the length of the body can in no way be altered without affecting the said value.

divisions of the wheel to 1-100th of 1-500th of an inch, *i. e.* 1-50,000th of an inch.

Example III.

With another object-glass, *cæteris paribus*, I find that one division on the stage is equal to two and a half divisions on the mother-of-pearl micrometer, or ten of the stage micrometer, to twenty-five of that in the eye-piece; therefore, with this object-glass, the value of one of the divisions in the field is the 1-2500th of an inch. On drawing out the eye-tube until ten divisions of the stage micrometer exactly cover thirty of the field one, the value of the latter becomes equal to the 1-3000th of an inch; further, until they cover thirty-five, 1-3500th; further, until they subtend forty, 1-4000th of an inch: *the value being obtained in every interval, be it what it may, by multiplying* 100 *by the number of divisions in the eye-piece covered by* ten *of those on the micrometer on the stage,* which I always suppose to be 1000 parts to an inch. In this way the value of any divisions on the eye-tube may be computed.

Example IV.

I now have recourse again to the cobweb micrometer and a deep object-glass, every thing else being as already stated. I find that I must turn the wheel round fifty times* before the cobwebs open sufficiently to include ten divisions of the micrometer on the stage, reckoning from the *centre of the said divisions*, which are now so much magnified as to make this precaution very necessary: therefore the value of the revolution of the wheel is now rendered equal to 1-5000th of an inch, and the divisions on its circumference to 1-100th of 1-5000th,

* There usually is in cobweb micrometers, on the superior part of the field, a set of teeth, the interval of which is equal to that of the threads of the screw, to shew us how often the wheel has revolved, the said teeth commencing from the immoveable cobweb, or zero of the scale.

or 1-500,000th of an inch, a quantity which I am afraid the eye can never estimate or discern with any power so as to measure it correctly, though the micrometer certainly may indicate it. It would perhaps be advisable to have the tire of the wheel made broad enough to admit of four sets of divisions, over which the indicator should extend with a sharp edge: one set dividing the circumference into 100 parts, the second into 50, the third into 20, the fourth into 10 only. We should then have the option of reading off the divisions either as 500,000ths of an inch, 250,000ths, 100,000ths, or 50,000ths; the last quantity being one which can be measured with perfect certainty.

It is sometimes customary to have the bar of a microscope or engiscope converted into a micrometer for measuring the depth of cavities, the thickness and foci of lenses, &c. by having proper divisions executed upon it, with a nonius attached to the socket of the stage; and sometimes when the stage has a transverse rack or screw movement, it is also divided, in like manner, to serve the purpose of a micrometer. I do not much admire the latter expedient; the former may frequently be useful.

As natural micrometers, grains of sand, human hairs, and the lines on the scales of butterflies and beetles, previously measured, may be used in cases of emergency, where better tools cannot be had.

DESCRIPTION OF A NEW MICROMETER.

I shall now proceed to describe a new kind of micrometer for simple and compound microscopes, which it appears to me has been long a desideratum in instruments for viewing real objects, and which, consequently, *do not admit of a real micrometer placed in the same plane with them*, so that the observer can seldom or never see his measure, and what he measures in focus at the same instant, unless with low powers.

Let a mother-of-pearl or hair micrometer be attached to the end of a tube, about six inches long, and an inch in diameter, furnished with stops, to prevent any light from being reflected by its sides. At the other end a small achromatic object-glass, *adapted for parallel rays,* of about half an inch focus, and a quarter of an inch in diameter, is to be placed. In default of such object-glass, the *double* object-glass of an engiscope, or two combined, may be used *with the convex lens or lenses turned towards the micrometer.* Let this apparatus be inserted into the interior of a slider-holder, or fixed underneath the stage of a microscope, the object-glass having a motion up and down in the tube by means of rack-work, and it must be evident that it will be easy to bring the image of the micrometer at the end of the tube, which the object-glass will form, into the same plane with that in which the object happens to be situated when in focus, by merely adjusting the screw of the rackwork which moves the object-glass; so that whereas in the compound microscope we see *an image of the object, but a real micrometer in the same plane with it,* in our field of view, we shall in the simple microscope see *the real object and an image of the micrometer in the same plane, at the same instant**.

It is, moreover, obvious that whatever degree of delicacy and fineness the micrometer at the end of the tube may possess, the image of it, formed by a line of so short a focus as half an inch, placed at six inches distance from it, will always be far smaller and more delicate, and that the proportion it will bear to the real micrometer can always be

* If it should be objected that, in the case of this micrometer, the image of the divisions or hairs will be always *behind the object,* whether opaque or transparent, and that therefore we shall not see them well unless with very minute or very translucent objects, and with opaque ones not at all; the answer is, that all other micrometers applied to microscopes will be just in the same predicament; the great advantage possessed by the micrometers of engiscopes is, that being *before the image of the object,* they are effective under all circumstances.

determined by regulating the length of the tube; while the value of its divisions may always be ascertained by trying them against those of a real micrometer placed on the stage.

If the achromatic object-glass employed to form the image is a *bad one* (and be it observed no common lens will do at all), the image it gives will of necessity always be indistinct, so that we shall hardly see delicate hairs or cobwebs with it. Moreover, it will condense light in the plane of the object, which will cause great indistinctness in the vision of many highly diaphanous bodies, such as very delicate animalcules; but this defect may always be cured by placing a coloured glass (blue or neutral tint) over the end of the tube, to reduce the intensity of the illumination to the requisite standard.

It is of course not necessary for me to remark that this sort of micrometer may also be used with engiscopes, but I do not recommend it, because that in their field of view is a real, and consequently a better, thing. It is, moreover, effective upon all sorts of opaque objects.

A very simple, cheap, and good kind of micrometer, may be made in the following manner:—Get a scale made on a slip of wood, six feet long, similar to that of a foot-rule; let the inches be divided into tenths. This you may easily execute for yourself, on strips of drawing paper pasted together, and afterwards to the slip of wood. Fix this to the wall of an apartment, just in the axis of an engiscope or microscope placed on a table with its body or lens in a horizontal position; take a piece of string and measure off such a distance from the wall, for the site of the engiscope, as shall cause its field of view to appear to be of about six feet diameter; and consequently, *when you look with both eyes open*, to make the scale appear to cross the field just as a real micrometer would, placed in the field-bar; there must be a kind of arm, with an eye-hole in it, attached to the eye-piece of the engiscope or the magnifier of the microscope, *as a sight for the eye which views the scale on the wall*: and care must

be taken that this spectacle is placed parallel to to it when an observation is made ; moreover, the piece of string mentioned above must be carefully preserved, and constantly used, to measure off the place for the eyes, and determine their distance rigorously from the scale when measurements are to executed, and the instrument is set up for such purposes. The value of the divisions on the scale is to be determined precisely in the same way as of those really placed in the field of view, on which subject I have already fully treated. By removing the instrument nearer to or farther from the wall, the value of the scale is increased or diminished at pleasure.

We thus get a scale of divisions which may be executed with the greatest nicety, *being on a large scale, though it does the work of a small one;* which may also be numbered and divided by leading strokes, in a way which will enable us to read it with the greatest facility, however dark the field of view may happen to be. Moreover, with a simple or compound magnifier of the highest power, it will always be distinctly seen when the object is perfectly in focus.

It would be an improvement to place the scale across a hoop covered with white paper, of the size of the field of view, and so placed as apparently to cover it; for then the image would not be confused by extraneous objects seen by the eye employed to look at the scale, and the effect of the whole would be very like that of a solar microscope.

I need scarcely add that the body of the engiscope and the magnifiers used with this micrometer must be *altogether fixed and motionless;* all the necessary adjustments must be given to the stage;—on this account the species of micrometer just described is well adapted to the Amician reflector and to horizontal achromatics.

APPLICATION OF MICROMETERS.

I shall now proceed to explain the use of micrometers in ascertaining the foci and power of lenses: my more learned

readers will excuse me if I am more explicit than there is any occasion for on their account, because I hope ladies, and perhaps even schoolboys, will do me the honour to read this treatise.

It is not quite so easy to measure the focus, either solar or visual, of a lens as it may appear at first sight. Nothing, indeed, appears more simple if we have a microscope with a bar very finely divided, and a nonius attached to the socket of the stage, than to lay a lens upon the stage, and reflecting the image of a distant object upwards, by a plane mirror, to measure the distance of the plane of the stage from the locality of the said image; and also that of the plane of the stage from some minute body placed on the upper surface of the lens, which will be equal to its thickness; and then to deduct one half of the thickness from the distance of the plane of the stage from the place of the image, which many persons suppose gives the correction for the thickness. This, however, is not the case, for there is no form of lens usually made whose focal distance can be measured *correctly* from the middle of its thickness, though the curves of such a one might indeed be calculated: the true correction for the thickness cannot be got without a deeper knowledge of the science of optics than can reasonably be expected from the generality of the persons who read this book: such as are curious on the subject I therefore beg to refer to Mr. Coddington's work on the "Refraction and Reflection of Light," pp. 89—102, which will give them every information requisite on the subject. There are, however, other methods of arriving at the true foci of lenses, which are *altogether practical*, and to which the most fastidious and exalted mathematician can hardly raise any objection; namely, *by measuring the power they give to a telescope when used as eye-glasses to it.* A small Newtonian reflecting telescope is the most proper for this purpose, because we shall have no thickness in the objective part to disturb us in measuring its true solar focus, which may be effected with

great accuracy by removing its plane metal, and receiving the image it forms of the sun on a disc of white paper placed in its axis, the distance of the solar image from the centre of the metal being the true focus, which must be very accurately measured: if this should turn out to be some round number it will be very convenient, but it is hardly to be expected. The method of operating then is as follows:—The plane metal is to be replaced, (which, if of accurate figure, will cause no alteration in the focus,) and the lens whose focus we wish to explore, must be attached as an eye-piece, and the instrument adjusted to distinct vision on a star, or some very distant object: then, with a dynameter, measure the size of the visual pencil, (which is, in fact, an image of the object metal or glass seen beyond the eye-piece,) and see how often it is contained in the acting diameter of the metal: this gives the power. You have then only to divide the focus of the metal by the power, and you obtain the true focus of the eye-glass, *or lens, whose focal length you wanted to measure.* Thus, if the length of the focus of the metal is 3 feet, and the power turns out to be 36, you may rest assured that the focus of the lens must be 1 inch, and so on.

As under ordinary circumstances the quantities in this method of mensuration are most likely to occur in a fractional form, I here give an example of that kind:—

Q.—The true sidereal focus of an object-metal, or achromatic object-glass, is $29\frac{1}{2}$ inches, its aperture $2\frac{1}{10}$ inches, and the size of its visual pencil, measured by one of Ramsden's dynameters*, 19-10,000ths of an inch: what is the solar focus of its eye-glass?

* This elegant little instrument (now rarely made) is composed of a divided plano-convex lens, about $\frac{1}{10}$ inch focus, attached to a micrometer screw, with a nonius dividing an inch into 10,000 parts. On turning the head of the screw (previously adjusted to 0), the pencil instantly begins to separate into two semicircles of light; and when their extreme edges are brought into contact, the divisions may be read off in 10,000th of an inch. I may observe that *mathematicians say the powers of telescopes are not obtained*

$$\text{F. } \overset{\text{In.}}{29\tfrac{1}{2}} = \frac{59}{2} \qquad \text{A. } \overset{\text{In.}}{2\tfrac{1}{10}} = \frac{21}{10}$$

Dividing the aperture by the visual pencil, we have $\frac{21}{10} \div \frac{19}{10{,}000} = \frac{21}{10} \times \frac{10000}{19} = \frac{210000}{190} = 1105\frac{5}{19}$ the power.

Dividing the focus of the object-glass by the power, we get $\frac{59}{2} \div \frac{21000}{19} = \frac{59}{2} \times \frac{19}{21000} = \frac{1121}{42000}$ the focus of the eye-glass for parallel rays being about 1-38th of an inch.

Now, madam, you will say you do not care a straw what focus the lens has,—*you only wish to know exactly how much it magnifies.* I regret to acquaint you that I am afraid we shall never be able to tell you this with anything like accuracy, because the standard of human sight varies so extremely in different individuals, and again in the same person at different periods of life; so that unless your ladyship will be content to

with absolute accuracy by this method, though it gives the ratio of one power to another with perfect exactness; therefore, if it is thought worth while, the power of the telescope may be got by *actual measurement*, thus:—Select a well-built smooth brick wall, and set off an accurately divided scale upon it, in white paint, or with a white chalk crayon: let the divisions be about 3 inches apart, or of such magnitude that they can be distinctly seen 40 or 50 yards off. Place the telescope at this distance from the wall, and adjust it upon one of the divisions; then, looking with one eye at the scale on the wall, and with the other at the magnified division in the telescope, see how many of the divisions on the scale it subtends; and if it does not exactly subtend a certain number, increase or diminish the distance of the telescope from the wall until it does: the number subtended is, of course, the power of the telescope upon a *near object*. It will now be necessary to measure the *acting focus* of the instrument under the existing circumstances; or to *ascertain how much its focus has been elongated from what it was on an infinitely distant object, and to add this quantity to the sidereal focus.* Then, dividing the focus so obtained by the power, we must have the focus of the eye-glass as nearly as it is possible to ascertain it: and having once got the correction for the dynameter with one power, it can be easily applied to any other.

know the power it gives to *your own eye*, or that of *some other person in particular*, your curiosity will be likely to remain unsatisfied; but all this shall be duly settled hereafter. In the meantime, allow me to remark that it were much to be wished that microscopists and opticians would leave off prating about the powers of their microscopes altogether, and confine themselves to speaking of their foci; or if of engiscopes, to the foci of single lenses having the same power: we should then know what they were talking about. Thus, a zoologist would express himself very like a man of sense and science if he would be pleased to acquaint us that he was observing such an object with a doublet of 1-30th of an inch solar focus, or with an engiscope whose power was equal to that of a single lens of 1-30th of an inch focus, &c. &c; mentioning also, perhaps, the angle of aperture his instrument had;—this is speaking *point-blanc*. But if, instead of this, he merely says he employed a power of 300 diameters, or 30,000 in superfices, or 9,000,000 in solidity; unless he also mentions the standard of sight it is his will and pleasure to compute by, we are left in the dark as to what the focus of his instrument might have been, and consequently cannot estimate its real character. As to the puerile custom many observers have, of giving the power of their instruments in superficial measurement instead of diametric, as it is intended *ad captandum vulgus*, so it answers no other purpose. Let any man endeavour to give some tolerable reason why the powers of telescopes should not be computed by the number of times they magnify the diameter of an object, but by the square of this number, or its cube, and I will admit the propriety of the practice as applied to microscopes.

But to return from this digression: I here proceed to give a few examples of the method of finding out the *solar* focus of other lenses when we have once duly ascertained that of one.

Convert the standard lens, supposed to be of one-inch focus,

into the object-glass of an engiscope having a micrometer in its field of view, and observe to how many of its divisions one of another micrometer placed on the stage of the instrument is equal*.

Now let us suppose, for example's sake, that one of the divisions of the micrometer on the stage happens to cover or subtend five of those on the field-bar, or that you can make it do so by pushing in or drawing out the eye-tube a little: well; affix the lens whose focus you want to know exactly in the place of the one inch lens aforesaid, *taking great care that it is exactly at the same distance from your field-glass as the former lens was, and the body precisely of the same length as before.* Let us suppose, on trying it, one division of the same micrometer before used on the stage subtends ten divisions of that in the field-bar: here must clearly be a lens of twice the power, or one-half the focus of the one inch,—that is to say, half an inch. In like manner, had it subtended twenty divisions, it must have been 1-4th of an inch focus; or if 40, 1-8th; if 80, 1-16th; if 160, 1-32d; and so on.

The solar focus of compound magnifiers may be tried precisely in the same way, taking care that their second or third glass, or that placed next the eye, is in the place of the object-glass; and the distance from it to the field-glass the same as when the standard lens was used.

More frequently, however, it happens that things do not go on so smoothly as I have here supposed; and the lens whose focus you want to measure will produce an image of the division of the micrometer on the stage, which is equal to some fractional number which is no multiple of the number of the divisions given by the standard lens. Thus, suppose it should

* When a deep object-glass is used, it frequently occurs that the lines on the micrometer placed on the stage are so much magnified as of themselves to subtend several of those in the field-bar; in this case care must be taken *to reckon from the middle of them*, as nearly as may be, in comparing them against the others, or the error will be very considerable.

subtend $17\frac{1}{2}$ divisions, you will only be able to arrive at the focus by a proportion, or little rule-of-three sum in vulgar fractions, thus :—

$$\begin{array}{lcccc} & \text{Div.} & & \text{Div.} & & \text{Inch.} \\ \text{As} & 17\tfrac{1}{2} & : & \dfrac{5}{1} & :: & 1 \end{array}$$

$$17\tfrac{1}{2} = \frac{35}{2}$$

$$\frac{5}{1} \times \frac{1}{1} \div \frac{35}{2} = \frac{5}{1} \times \frac{2}{35} = \frac{10}{35} = \overset{\text{Inch.}}{\frac{2}{7}} \; \textit{Ans.} \text{ or } {\cdot}285{+}\text{Dec.}$$

In another case, using a lens of $\frac{2}{10}$ or $\frac{1}{5}$ inch focus for the standard lens; the image of the one to be measured subtends 50 divisions, while the $\frac{2}{10}$, or standard image, subtends 14 :

$$\begin{array}{lcccc} & \text{Div.} & & \text{Div.} & & \text{Inch.} \\ \text{As} & \dfrac{50}{1} & : & \dfrac{14}{1} & :: & \dfrac{1}{5} \end{array}$$

$$\frac{14}{1} \times \frac{1}{5} = \frac{14}{5} \div \frac{50}{1} = \frac{14}{5} \times \frac{1}{50} = \frac{14}{250} = \overset{\text{Inch.}}{\frac{4}{125}} \; \textit{Ans.}$$

or nearly $\frac{1}{18}$ of an inch.

If you use the focus of a very deep lens to measure that of a shallow one, then, of course, the longer the focus the fewer will be the divisions its image will subtend on the micrometer of the field-bar, compared with that of the short one: thus, if the image of a division, given by a 1-60th inch lens, subtends 120 divisions on the field-bar, a 1-inch lens will only cover two with its image: where fractional quantities occur, the focus must be obtained in the same way as before. Another method of getting at the true solar foci of lenses, is to make them the object-glasses of a *diminishing telescope*, in-

stead of an engiscope, and measure the size of the image of some comparatively distant object with them, such as a window, or one of its panes, exactly in the same manner, and upon the same principle, as before, by means of a micrometer in the eye-piece of the miniature telescope; but this method I do not recommend—it is not so accurate as the other, because we have to work on a smaller scale, and is only applicable, perhaps, to lenses of excessive depth, which give so dark or so indistinct an image in the engiscope, that the divisions on the micrometers or their cobwebs cannot be well seen. I shall, however, append one example of this mode of measurement*.

Example I.

A lens, whose known focus is 1-19th of an inch, happens to make the image of a window seen from a distance of three yards, subtend $131\frac{1}{2}$ divisions on a micrometer in the field-bar of an erecting eye-piece, employed to examine the image: another lens, at the same distance, gives a spectrum which subtends only $43\frac{3}{4}$ division: what is the focus of the latter?

$$131\tfrac{1}{2} = \frac{263}{2}$$

$$43\tfrac{3}{4} = \frac{175}{4}$$

$$\frac{263}{2} : \frac{175}{4} :: \frac{1}{19}$$

$$\frac{175}{4} \times \frac{1}{19} = \frac{175}{76} \div \frac{263}{2} = \frac{175}{76} \times \frac{2}{263} = \frac{350}{19988} =$$

$$\frac{175}{9994} \text{ or nearly } \frac{1}{57} \text{ of an inch.—}\textit{Ans.}$$

* When plano-convex lenses have their foci measured in this way, the convex side must be turned towards the parallel rays, or their foci will come out too long.

I suppose I must now give some statement or other about the power of lenses, or my readers will not be content; but how am I to determine the standard of sight upon equitable principles? This is, in fact, the only obstacle, but a proper tough one it is; and a stumbling-block it must remain to the end of the world.

I have, then, made many experiments upon young persons in the full vigour of health and strength, whose eyes were perfect and highly keen and good, and I find that the average of their standard of sight *upon minute objects* is much less than ten or even eight inches (the usual standards), and *approaches nearly to five inches on the average:* many are able, with a little practice, to see most perfectly at about four, and I have repeatedly seen school-boys read with their noses touching their books, who were not in the least short-sighted, (for I of course exempt all long and short-sighted persons from any voice in determining a standard of sight); my own distance is six inches, at the age of forty; twenty years ago it was four inches and a half.

I am not in the least short-sighted, on the contrary I can see distant objects with the quickness of a savage. I fancy that I have seen several double stars which are very far separated with my naked eye, and I can almost always see the shot of a piece of ordnance when I fire it myself. I shall therefore construct a table of magnifying powers, for a standard of sight of 5 inches (which, as a *comparative* estimate, will be useful), and *they who do not like it, may double the quantities and standard of sight,* and then I hope they will have power enough. Much good may it do them.

First, however, I must premise, that lenses of all foci whatsoever, 100 feet for example, magnify somewhat, and so do even thick plates of refracting substances having plane surfaces; because, when placed before the eye, they increase the refraction of the rays of light impinging upon it, and thus

enable us to view objects under a larger angle than we could otherwise do.

What may be called the visual focus of a lens, or its distance from an object upon which we have adjusted its focus as a magnifier differs always widely from its focus, when used to collect the parallel rays of distant objects into an image of them, after the fashion of the object-glass of a telescope; yet these two kinds of foci have always been confounded together by opticians, and it is general considered, as a matter of course, that a lens which brings parallel rays to a focus two inches distant from it, will, when used as a magnifier, preserve a visual focus of two inches, *with a little allowance for different sights*; but nothing can be more erroneous, as both theory and experiment well demonstrate.

METHOD OF FINDING THE VISUAL FOCI OF LENSES, THEIR FOCI FOR PARALLEL RAYS, AND THE FOCUS OF THE EYE BEING GIVEN.

In order to discuss this subject in its right point of view, *we must begin by considering the naked eye itself as a magnifier, having power equal to that of a lens of its own shortest visual focus; and when a magnifier is placed before it, it must be treated in the light of the anterior lens of a doublet, and the focus and power of the combination must be found precisely in the same manner*, viz., we must multiply the shortest visual focus of the eye by the sidereal or solar focus of the lens whose power we wish to learn, and divide the product by the sum of the two foci, minus the distance between them, which gives the focus of a lens whose power is equal to the combination, which may then be ascertained by seeing how often the said focus is contained in the visual focus of the eye. This method will be found to agree extremely well with experiment; but if we consider the lens and the cornea

in contact, and make no allowance for distance, as we shall most likely think ourselves justified in doing, the focus will turn out somewhat too short, and the power consequently too high. If we consider them in absolute contact, and the distance between $= 0$, we must of course suppose them divested of thickness, or one of them at least, which can never be; the thickness, therefore, must always be reckoned as so much distance: besides which we well know that we cannot endure any lens to touch the cornea of the eye, even if the eyelashes and eyelids would permit it, therefore the distance must always be equal to something, though, for my own part, I do not think it worth while to take it into consideration.

I shall give an example or two of this method of computation.

Q.—What is the power of a lens of seven inches solar focus used by a person the shortest visual distance of whose eye is six inches?

$$6 \times 7 = 42 \qquad \text{Distance} = 0$$
$$6 + 7 = 13$$

$$42 \div 13 = \frac{42}{13} = 3\tfrac{3}{13}$$ Inches, the focus of the eye and lens combined, or the *visual focus.*

$$\frac{6}{1} \div \frac{42}{13} = \frac{6}{1} \times \frac{13}{42} = \frac{78}{42} = 1\tfrac{6}{7}$$ times.—*Ans.*

Q.—What is the power of a lens of 1-inch focus, computed by a standard of six inches?

$$6 \times 1 = 6$$
$$6 + 1 = 7$$

Inch.

$\frac{6}{7}$ therefore is the visual focus.

$$\frac{6}{1} \div \frac{6}{7} = \frac{6}{7} \times \frac{7}{6} = \frac{42}{6} = 7$$ times.—*Ans.*

In this manner any person may settle the power of a lens, *as far as his own particular eye is concerned,* with considerable exactness, but he must not measure his neighbour's corn by his own bushel.

I must observe that if the power of a lens is low, as, for example, two inches focus or more, it is not easy to find its visual focus very exactly, even with such a delicate object as a small globule of quicksilver; for *there will appear to be considerable space over which it may be moved without causing the star to swell out into a disc, either within or without the focus:* in making the experiment, I have, therefore, always selected the *shortest distance* at which the star seems perfectly sharp and free from coma, *just before it swells out when placed within focus;* and I ascertain the visual focus of the eye in the same way. I request my reader particularly to recollect, that in the following table the power is given according to *the visual focus* of the lens, not its sidereal or solar one, and that *the power of a lens, rated by its solar focus, is always under the truth,* especially if the focus is a long one. I believe it wholly impracticable to ascertain the power of lenses *without reference to a standard of sight,* as may be done with telescopes, and likewise in the case of the solar microscope.

TABLE

OF THE POWERS OF LENSES OF THE FOCI GENERALLY MADE BY OPTICIANS, RATED BY A STANDARD OF SIGHT OF FIVE INCHES.

Visual Focus.	Power in Diameters.	Visual Focus.	Power in Diameters.
Inches.		Inch.	
2	$2\frac{1}{2}$	$\frac{1}{16}$	80
$1\frac{7}{8}$	$2\frac{2}{3}$	$\frac{1}{17}$	85
$1\frac{3}{4}$	$2\frac{6}{7}$	$\frac{1}{18}$	90
$1\frac{5}{8}$	$3\frac{1}{13}$	$\frac{1}{19}$	95
$1\frac{1}{2}$	$3\frac{1}{3}$	$\frac{1}{20}$	100
$1\frac{3}{8}$	$3\frac{7}{11}$	$\frac{1}{25}$	125
$1\frac{1}{4}$	4	$\frac{1}{30}$	150
$1\frac{1}{8}$	$4\frac{4}{9}$	$\frac{1}{35}$	175
1	5	$\frac{1}{40}$	200
$\frac{7}{8}$	$5\frac{5}{7}$	$\frac{1}{45}$	225
$\frac{3}{4}$	$6\frac{2}{3}$	$\frac{1}{50}$	250
$\frac{5}{8}$	8	$\frac{1}{55}$	275
$\frac{1}{2}$	10	$\frac{1}{60}$	300
$\frac{3}{8}$	$13\frac{1}{3}$	$\frac{1}{65}$	325
$\frac{1}{4}$	20	$\frac{1}{70}$	350
$\frac{1}{8}$	40	$\frac{1}{75}$	375
$\frac{1}{10}$	50	$\frac{1}{80}$	400
$\frac{1}{1}$	55	$\frac{1}{85}$	425
$\frac{1}{12}$	60	$\frac{1}{90}$	450
$\frac{1}{13}$	65	$\frac{1}{95}$	475
$\frac{1}{14}$	70	$\frac{1}{100}$	500
$\frac{1}{15}$	75		

THE POWER OF ENGISCOPES

Is very easily ascertained: we have only to place a micrometer on the stage, having the same divisions as that in the field-bar, and to observe how many of the divisions of the latter are subtended by one of those of the micrometer on the stage (which of course shews the number of times the image is magnified), and to multiply the number of divisions by the power of the eye-glass, whether single or double, ascertained by the preceding rules: *in this case the field-glass or glasses (for there are sometimes two) must not be associated with the eye-glass when its power is calculated, because the field-glass co-operates with the object-glass in forming the image, which is magnified solely by the anterior lens or lenses.*

Example.—In an engiscope, with a particular object-glass, one division of a micrometer on the stage subtends $13\frac{1}{2}$ of those on the field-bar; and the *visual* focus of the double eye-glass is found to be one inch and a quarter: required the total power, computing by a standard of sight of five inches—

$1\frac{1}{4} = \frac{5}{4} \quad \frac{5}{1} \div \frac{5}{4} = \frac{5}{1} \times \frac{4}{5} = \frac{20}{5} = 4$ power of eye-glass.

Then $13\frac{1}{2} \times 4 = 54$ Total power.—*Ans.*

Second Method—*Treating the Engiscope as a Single Lens.*

View the image of some distant object, a window for example, formed in the visual pencil of an engiscope, with a dynameter of very delicate divisions, and see how many of

them it subtends: view the image of the same object formed by some lens of known focus, in the same manner with the same dynameter, *taking care that the object-glass of the engiscope and the lens are at the same distance from the object*, and see how many divisions the latter image subtends; then, by comparing them against each other, we learn to what single lens the engiscope is equal in focus and power.

Example.—The image of a window in the visual pencil of an engiscope subtends 14 divisions; that of the same object, formed by a lens of 1-5th of an inch solar focus, 50; what is the power of the engiscope rated by a standard of sight of five inches?

$$\text{As } \frac{50}{1} : \frac{14}{1} :: \frac{1}{5}$$

$$\frac{14}{1} \times \frac{1}{5} = \frac{14}{5} \div \frac{50}{1} = \frac{14}{5} \times \frac{1}{50} = \frac{14}{250} = \frac{7}{125}$$

solar focus of a single lens of the same power as the engiscope. We have now, therefore, to find the visual focus of a lens having a solar one of 7-125ths, by the preceding rules.

$$\frac{7}{125} \times \frac{5}{1} = \frac{35}{125}$$

$$\frac{7}{125} + \frac{5}{1} = 5\frac{7}{125} = \frac{632}{125}$$

$$\frac{35}{125} \div \frac{632}{125} = \frac{35}{125} \times \frac{125}{632} = \frac{4375}{79000} = \frac{35}{632} \text{ visual focus.}$$

Five Inches (standard of sight) divided by $\frac{35}{632} =$

$$\frac{5}{1} \times \frac{632}{35} = \frac{3160}{35} = 90\tfrac{2}{7} \text{ times.}$$ *Answer.*

THIRD METHOD.—The principle of this is, *that the diameter of the visual pencil of an engiscope bears the same proportion to the focus of a lens equal in power to the engiscope, that the diameter of the object-glass of the said engiscope bears to its anterior conjugate focus.*

Thus let us suppose we know that a certain object-glass, or metal, or a series of object-glasses, *used with a certain stop,* has $18\frac{1}{3}^\circ$ of aperture (for the method of measuring the angle of aperture, *vide* "Microscopic Cabinet"): this, in other terms, denotes an object-glass whose aperture is equal to 1-3rd of its anterior acting focus; and that we find, by measurement with a dynameter, that with a certain eye-piece its visual pencil is 3-200ths of an inch in diameter;—required the power of the engiscope? Here we must multiply 3-200ths of an inch by three, which gives 9-200ths of an inch for the solar focus of a lens equal in power to the engiscope; the visual focus of which must be ascertained according to the examples already given, and compared with the standard of sight.

If the angle of aperture had been $27\frac{1}{2}^\circ$, then the diameter of the visual pencil must have been multiplied by two; had it been 55°, the diameter would have been equal to the solar focus of the equivalent lens, so that in this case we should have merely to find its power.

The length of the anterior focus of an object-glass, with a body of any determined length to which it may be attached, may be got at as follows:—Take out the eye-piece, and presenting the body with its object-glass in its place towards the sun by tilting it to its proper angle, ascertain the solar focus of the said object-glass by placing a flat surface on the stage of the engiscope to receive the image of that luminary. When the stage has been duly adjusted to this focus, make a mark on the bar, against the socket of the stage, with a needle; then attach the body to the object-glass, and adjust its focus

upon the same flat surface which received the sun's image. *It will now become longer*, and a fresh mark must be made against the side of the socket; then measure very carefully the space between the two marks, and add it to the length of the solar focus of the object-glass found by some of the preceding methods;—*the sum is the length of the anterior conjugate focus of the object glass, &c.* When this is ascertained, by measuring the exact size of the stop behind the object-glass, or its interior diameter, if it has none, and making a diagram on paper, the angle of aperture may be ascertained, and the power of the instrument measured by the third method given above, without having recourse to a regular instrument for measuring angles of aperture.

OF MEASURING THE SIZE AND ANGLE OF THE FIELD OF VIEW OF ENGISCOPES.

1*st Method.*—Having ascertained the visual focus of the eye-glass, or eye-glasses, if a double one is used, measure the diameter of the field-bar, and multiply it by the power of the eye-glass.

2*d Method.*—Hold a foot-rule at your own shortest visual focus against the body, and look at it with one eye, while you look through the instrument with the other, and note where the edges of the field cut the divisions on the rule.

3*d Method.*—Attach a camera lucida, or a diagonal bit of speculum metal, or thick glass, to the ocular end of the engiscope, and placing the body in an horizontal position, fix a sheet of paper underneath it at your particular visual focus; then with a pencil mark the edges of the field on the paper, and measure the distance between them. In order to obtain the angle, or number of degrees your field takes in, make a diagram on paper, thus:—Let the width of your field, taken at any distance from the eye-piece by this third method, form

the base of the triangle, bisect this, and erect a perpendicular on it, marking a point for the apex of the triangle, at the distance of the axis of the body or visual pencil from the base; then complete the legs, and measure the angle they form with a protractor: it would be best always to speak of the *number of degrees taken in by any instrument, instead of the absolute width of the field of view*, because the angle is not affected by difference in the visual focus, and is therefore a constant quantity.

Another very simple method of ascertaining the angle of the field is by holding the eye-piece up to one eye, and looking against a wall with the other; then noting the size of the circle of light, and making two marks by driving two nails into the wall, denoting the diameter of the field; then take a bit of twine, tie its ends to the two nails, and stretch the strings, *bringing them together precisely at the point of sight you used in taking the breadth of the field of view;* measure the angle they form, with a protractor, and you have the angle of vision: or the same thing may be effected by taking a sector or foot-rule, applying the joint to your eye, and opening the legs out till they come into a line with the two nails, when the angle is to be measured as before.

This operation may be performed on the small scale by taking the exact width of the field-bar, and constituting it the base of a triangle, of which the apex is to be the end of a line at right angles to the middle thereof, of the exact length of the visual focus of the eye-glass: the angle thus formed is to be measured like the rest.

It is easy to chalk a scale on a brick wall, or it may be made in the small way on a slip of wood, which, from a particular point of sight, will shew at a glance the angle of vision, by looking at it with one eye, while the eye-piece is held to the other, so that its field shall cover the scale.

As many persons may like to know how to ascertain the solar focus of a lens, from knowing its radii and the refrac-

tive power of the glass it is made of, and its radii from knowing its focus, &c. I append a method of ascertaining the same, from the inestimable work of Mr. Coddington on Reflexion and Refraction, p. 293. For this purpose we have only to divide the radius by the index of refraction, minus 1.

Example.—Required the focal length of a plano-convex lens, made of crown glass, having a refractive index of 1.525, the radius being $\frac{3}{4}$ inch.

$$1{\cdot}525 - 1 = {\cdot}525$$
$$\tfrac{3}{4} = {\cdot}750 \text{ dec.}$$
$${\cdot}750 \div {\cdot}525 = 1{\cdot}428 \text{ focus.—}\textit{Ans.}$$

Example 2.—An equi-convex lens is desired of the same focal length (1·428), made of the same glass; required the radius. In this case the index of refraction, minus 1, is multiplied by 2, and by the focus.

Thus, $\cdot 525 \times 2 \times 1{\cdot}428 = 1{\cdot}643$ radius —*Ans.*

I have now, I trust, given the public at large the means of determining the power of microscopes and engiscopes, with a much greater degree of accuracy than has hitherto been done; perhaps with all the exactness practicable, though, as I have already said, it would be better to abstain from discussing their powers altogether, and to speak only of their *solar* foci, which are constant quantities.

C. R. G.

CHAPTER III.

ON

MONOCHROMATIC ILLUMINATION.

To the illustrious Sir David Brewster we are indebted for the scheme of illuminating microscopes by monochromatic or homogeneous light, in order to render their chromatic aberration insensible, which, it must be confessed, appears *à priori* extremely plausible; nevertheless, there are many objections to it. It is evident that all sorts of monochromatic illumination whatsoever must be far less intense than the ordinary kinds, inasmuch as they must consist of one of the seven constituent prismatic colours abstracted from the rest; for if a beam of light is divided into seven parts, and only one of them is taken (though it should be the brightest of the set), it must follow that it will be far fainter than the combination of the whole.

It is well known to practical men, that the most vivid white light which can be procured (barring always that of the sun), is by no means too brilliant for opaque objects; it can need, therefore, no argument to shew that, at all events, monochromatic light can never answer effectively for these, however much it may be condensed; with certain transparent ones, seen with low powers and large apertures, it performs tolerably well, and is extremely useful when we wish to examine the spherical aberration of uncorrected lenses, divested of the chromatic species. Monochromatic light must of course

always be of some colour or another, which circumstance must necessarily produce a very fallacious appearance in the vision of many objects, which will compel the observer to examine them afresh with white light, in order to rectify their apparent tints. I myself am convinced that a *real absolute* monochromatic light is yet to seek, and shall here state the experiments on which I found my opinion. When white light is subjected to the action of a prism, it is well known that it is dispersed or resolved into seven prismatic rays, leaving a number of colourless lines, when the experiment is made with due delicacy, in the method prescribed by Fraunhofer. Now I think if there is any such thing as monochromatic light, a good prism *ought* to be able to produce it, and accordingly I have chosen light so generated for my experiments.

The white light of the sun, reflected by a plane mirror, is able to shew most of the coarser proof-lined objects in a rough manner: indeed, I have sometimes succeeded in bringing out the straight lines on the podura with it, and this too with an instrument which had not the power of shewing them with any other species of illumination. I therefore choose this class of objects in my trials with solar light, for they are, upon the whole, exhibited better in proportion by it than any other bodies. In order to obtain from the solar beam a monochromatic illumination, I made the following arrangements: I placed an engiscope with its body in a horizontal position, and excluded all white extraneous light from it, as follows: I attached a tube, six inches long, to the stage, and at the end of it fixed a diaphragm 1-8th of an inch in diameter; in the prolongation of the axis of this tube, and at about a foot distance from it, I hung up a piece of black silk velvet; I likewise drew a shade over the objective end of the microscope reaching close down to the slider, so that no light should get into the body of the instrument by reflection. By these means when its power was equal to that of a 1-20th of an inch lens, my field of view was perfectly dark and invisible; I then in-

troduced a prism* (the edges and other parts of which not employed to refract light, were carefully blackened, that no white light might be reflected or radiated by it), between the piece of black velvet and the tube, so as to refract the light of the sun from a mirror into the microscope. The prism was placed vertically, so that either of the seven colours it produced could be brought to bear upon the small aperture at the end of the tube, to the exclusion of the rest, the spectrum being of considerable breadth, owing to the distance of the prism from the diaphragm, which was about three feet. Now by this apparatus I could very easily select any one of the colours I wanted, by merely moving the microscope a little to the right or left, and illuminate the object with it. The object-glass which I made use of was a common plano-convex of half an inch focus, and a quarter of an inch of aperture, which, with the white light of the sun, was just able to shew the lines upon the scales of the Menelaus butterfly in a very imperfect manner, and was much disappointed and surprised to find that no amelioration in the vision was produced by using any of the prismatic colours, instead of the white light. Moreover, I found *that not one of the colours produced apparent achromatism, unless it truly perforated the axis of the microscope,* any obliquity of the light instantly causing prismatic fringes to appear, modified by the tint of the coloured ray used, *much in the same manner as white light would have been, if merely passed through a piece of coloured glass.* Now the lined objects always require oblique light for their manifestation, and consequently never could be shewn without exhibiting other colours beside those of the primary ray employed; but other objects which agree with direct light could be shewn destitute of prismatic fringes, though very confused and indis-

* This was capable of shewing Fraunhofer's lines very well with the angle I used.

tinct. I may observe that the light of the sun treated in this way is by no means too intense for microscopic purposes. I even thought that the violet ray was not intense enough. The blue ray with an *achromatic object-glass* performs pretty well on the lined objects : I like it better than any of the rest, for it most resembles day-light, though each is capable of exhibiting the lines, *if not procured in a state of too great intensity*, by being taken too close to the prism. I repeated these experiments with the flame of a wax taper in a dark room, in the following manner:—I used the prism as before, and adjusted the wax-light to a proper height to suit it; I then carefully shaded the candle, so that none of its direct light should get into the microscope, and threw the spectrum formed by the prism into the body of the instrument, taking care to use it at such a distance from the prism that the light of the taper should be fairly dispersed. I did not use the long tube in these experiments, thinking it of no use, as the room was dark, and I could not see my field of view until the spectrum of the prism was directed into it. The light afforded by the taper was too faint for the power I used with the solar light; I was therefore obliged to reduce it one-half: even then the blue ray had not sufficient power; the yellow one had, and seemed little different in its effect from the taper itself in the same state of intensity. Suffice it to say, that I got the same results as before; that is, when I obtained the light of the prism perfectly *direct*, I obtained *achromatism ;* when it *came obliquely, the coloured fringes instantly appeared,* modified by the tint of the ray, and much in the same way as if I had looked through a coloured eye-glass at the image produced by common light. Wishing to sift this phenomenon to the bottom, I then used the light of the taper in its natural state, and found that *there is one particular position in which it may be placed behind the stage, so as to give apparent achromatism with any sort of microscope whatsoever, however chromatic it*

may be. This appears to be as nearly as possible in the axis of the microscope; if it is placed ever so little out of it, the coloured fringes instantly shew themselves.

I am confident that I could make an inexperienced person believe in the achromatism of any microscope whatever, by making this arrangement, *and a most fruitful source of deception it must prove as to the achromatism of these instruments.* I may observe that perfectly direct day-light also gives apparent achromatism with any common uncorrected lenses.

As prisms and lenses have a great analogy to each other in their operation, I then experimented on the dispersed solar light with them, and it always appeared to me that where I could succeed in getting the light from the diaphragm thown perfectly direct through a prism, no sensible secondary dispersion was produced; but when it came obliquely, the aperture was completely fringed by prismatic tints in their natural order. As it seemed to me that a piece of rubbed glass, placed over the diaphragm, caused the light to be equally diffused over the interior of the tube, whether it came obliquely or not, I tried the effect of the prism upon it, but the light always seemed to be dispersed in this way as before. (For these experiments I used the apparatus first described, only I took out the object-glass and eye-glass of the microscope, and looked at the diaphragm through a small prism, held in my hands at the ocular end of the body.) In order to have made these latter experiments with the prism properly, I should have required a heliostat moved by clock-work, for the motion of the earth subverted the direction of the solar beam immediately I had got it truly in the axis of the body of the microscope, and the power I possessed of counteracting this was only by means of adapting the prism to the motion of the light with my hands: I should have liked to have dispersed the colour a second time, and fairly produced a spectrum of it on paper, under the circumstances of direct and oblique incidence.

The impression produced in my mind, by reflecting on the facts stated, was, that *a certain quantity of white light enters into the constitution of each of the seven-coloured rays, as water does into the constitution of alcohol, and may be rendered manifest by the dispersive power of prisms and lenses, under the circumstances I have described:* and this view of the subject seems to acquire conformation from the "*New Analysis of Solar Light,*" by Sir D. Brewster, (vide *Edinburgh Journal of Science,* Vol. V. p. 197,) published subsequently to my paper on Monochromatic Light, in the said Journal, (of which the present tract is a corrected and modified second edition.) See also the original paper, and his remarks upon it, Vol. V. pp. 52, and 143.

Fortunately, however, notwithstanding all that I have said of the impossibility of obtaining monochromatic light from *the action of the most perfect prisms,* some kinds of lamps wlll produce it in *a sufficiently pure state for practical purposes,* though by no means deserving of the appellation of monochromatic, in strict scientific language. I shall merely mention two kinds:—The first is reckoned by Sir D. Brewster the best yet discovered; it consists in burning diluted alcohol, saturated with muriate of soda, in any suitable apparatus, applying heat at the same time to the solution; a faint *golden-coloured flame,* nearly invisible when presented against the light of a common candle, or of the sky, is the result: its intensity may be somewhat increased by using a double concentric Argand wick, or a long flat one, presented sideways, so as to have the effect of several lights placed in a row. I myself do not approve of using a multiplicity of lights, though adjusted in a line, for microscopic purposes, for very obvious reasons.

This golden-coloured flame, when analyzed by the prism, is perfectly monochromatic, *except that it shews green, blue, indigo, and purple light,* as the flames of other substances in combustion do; but *there is a remarkable want of the red and*

orange light. It is too faint to allow us to perceive any of the green, blue, indigo, or violet rays, which it certainly has in its constitution, when reflected or radiated from coloured objects, all of which appear to be some compound of black (which implies a negation of colour) with yellow, except that white bodies appear white, or nearly so; thus a printed book, or the dial-plate of a watch, appear just as they do when viewed by faint candle-light: the white ought, according to theory, to appear yellow, or rather gold-coloured; but we must consider that nothing in this world goes on just as it should do.

This species of lamp gives a very unsteady flame, which scintillates and sputters very disagreeably; I cannot say that I ever saw a proof-object with it.

Another sort may be made by dissolving borax in the strongest alcohol, (of a specific gravity not greater than 0.815). Borax usually imparts a green colour to the flame of alcohol, but treated in this way it gives a golden light extremely similar to the other; it does not require heat to be applied to it, and burns much more steadily. It is, however, somewhat capricious: thus, if burnt in a common thimble, its flame is pretty much like that of neat alcohol; if in a spirit lamp, it sets off at first with a flame, which shews traces of red and orange light, but as the wick becomes consumed, (which should be allowed to become pretty long, and be but little trimmed,) it gives the golden flame like the other, shewing only green, blue, indigo, and violet light, when subjected to the action of the prism: the best way, however, of burning it, is in a little brass cup, not more than 3-10ths of an inch wide, and the same depth, *without any wick at all;* this gives a strong flame of the right sort, but unfortunately it is soon expended: a lamp should therefore be contrived, having a fountain to keep this little burner constantly replenished; and in order to render the lamp really effective, an apparatus for feeding the flame with oxygen gas must be associated with

it*. This can easily be made by any workman accustomed to manufacture chemical implements: the light will then acquire the intensity requisite for microscopic purposes, and though it may prove of somewhat too expensive and troublesome a nature for ordinary use, will be of infinite service to the optician who wishes to be released from the trouble of contending with chromatic aberration, and may probably promote discoveries, by allowing us to use object-glasses in which the spherical aberration has been more exquisitely corrected than can easily be done where the foci of the convex and concave glasses must constantly be kept in a certain ratio to each other, which circumstance is a great drawback on the exertions of the workman, and is perpetually interfering with every step he takes for the destruction of indistinctness. It is well known that in all compositions of convex with concave lenses of flint glass, the curves which correct with a moderate aperture will over correct with a larger one; that, in short, the contrary aberrations of these two kinds of lenses can only be exactly balanced with small apertures: thus, when a very large angle of aperture is to be obtained, we are obliged to combine two, three, or even four pairs together: by thus dividing the refraction the evil is diminished, but a radical cure is evidently impossible. *Now, where achromatism is not a desideratum*, the concaves of flint glass may be dispensed with; for by combining a meniscus of particular curves with another lens, having a minimum of aberration, the spherical error may be got rid of equally well. To Sir J. Herschel we are indebted for the dimensions of two species of lenses of this description. —Vide *Phil. Transactions*, for 1821.

It must, however, be understood that the meniscus will only correct to a certain angle of aperture, (about the same that a

* Vide Mr. Talbot on Homogeneous Light; *Phil. Magazine*, for 1833. Vol. III. p. 35.

concave of flint-glass will,) after which the error begins to appear as before, *but is of a contrary nature;* viz. with a large aperture the composition is *under corrected* for spherical aberration: it would, however, seem probable, *à priori* at least, that by combining one of Sir J. Herschel's doublets with a lens consisting of a convex associated with a concave, a correction of the error of sphericity to a very large angle ought to be obtained. This experiment is well worthy of a trial; at all events, several pairs of Herschelian doublets would probably be associated with effect, since we know that regular achromatic combinations may, which will also act separately. A monochromatic light, therefore, being once obtained *in a sufficient state of intensity for practical purposes,* bids fair to conduct us to the highest perfection of which aplanatic object-glasses and magnifiers are susceptible.

According to the experiments of P. C., detailed in the "Records of General Science," for 1835, pages 34, 108, 172, and 351, the true monochromatic or primitive colours are *red,* (N.B. not *crimson,*) *green,* and *violet*: these, when *pure* and *undiluted* with white light, form the supposed primitive colours, *crimson, blue,* and *yellow,* as follows:—A union of violet and red, crimson; Green and violet, blue; green and red, yellow. Perhaps we may one day obtain green or violet-coloured glasses of a certain tint and intensity of colour, which will render the chromatic aberration of telescopes and microscopes insensible; though if this should be effected there is a chance of the remedy proving as bad as the disease.

C. R. G.

CHAP. IV.

ON SOLAR ENGISCOPES,

AND ON THE EXHIBITION OF TESTS BY THEM.

By a Solar Engiscope of course is meant an engiscope applied as the magnifier of a solar microscope, with a suitable apparatus. Persons of a contemplative turn of mind, familiar with optical studies, are seldom much gratified by the ordinary exhibitions of solar microscopes, even when equipped with achromatic magnifiers of the best construction. They see at a glance that the immoderate amplification of the image of these instruments is produced by permitting the rays to spread themselves, at the expense of the sharpness and light of the picture; and that *power so gained is not effective,* or capable of extending our insight into the nature of things, as it might do if obtained in a legitimate manner; that, in short, it only serves to raise a feeling of stupid wonder and admiration in the vulgar, and beyond its power of captivating them it has no real use whatever. Individuals of this cast will naturally turn towards the solar engiscope as an instrument capable of affording real gratification to a man of science, and lover of the fine arts: here is found magnifying power fairly obtained; a picture whose sharpness and clearness is a maximum, combined with a field of view of considerable extent. Whatever transparent objects can be seen distinctly with the optical part of a solar engiscope, when applied to the eye, can, with very

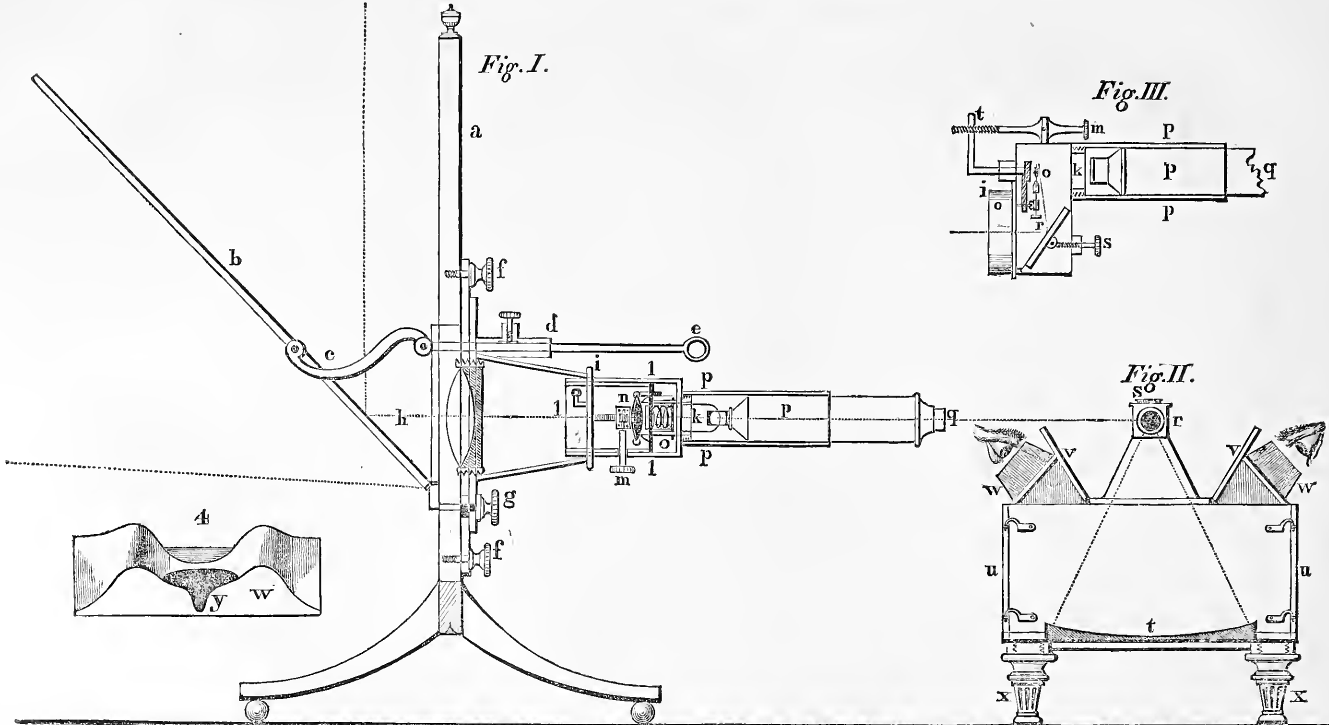
few exceptions, be seen also in the picture in the camera of the solar engiscope ; whatever traits are visible in the one method of using it are more or less visible also in the other ; and as these may be *contemplated by two or three persons at once,* where any dispute or difference of opinion may happen to occur as to their real character, it may be cleared up satisfactorily by their joint scrutiny. The pictures of opaque objects formed in the camera are, however, certainly rather pleasing and beautiful than useful ; for the amplifying power with them can never be carried to the extent necessary to shew their minutiæ satisfactorily, from the want of light, or the danger of burning the object if it is rendered sufficiently intense to create a strong image. Nevertheless, a vast number of the most remarkable features of these bodies may be exhibited ; and I have no doubt that many persons, well entitled to the appellation of philosophers, will consider the pictures of opaque objects as the most interesting part of the display.

I have used several species of stands or mountings for solar engiscopes ; the original one was altogether different from that now presented to the public : in this the light of the sun, first reflected from an heliostot, was thrown downwards by a plane oval mirror, the bar and body being vertical, and the image formed in a camera below. This answered very well with ordinary objects, and moderate powers, and was very easily convertible into the form of an ordinary engiscope ; but when very high powers were used with test objects, the *tremor* from the top-heavy construction of the instrument could not be subdued, and utterly marred the vision of very delicate lines. I then used the same construction in an horizontal position, by which means I got rid of the tremor, and likewise precluded the necessity of introducing the primary reflection from the heliostot ; but in order to get the oval mirror to reflect a round spot of light, I was obliged to expose the instrument

to the full rays of the sun, which was inconvenient on many accounts; more especially as the head and face of the observer were of course also exposed, and could not easily be shaded.

The construction I shall now describe is free from these inconveniences, and upon the whole, I think as good as any which can be contrived; and will moreover act as an ordinary solar microscope, when required. Fig. 1, in the annexed engraving, is a geometrical elevation of the instrument, one tenth of the real size. *The various parts are represented as if formed of transparent matter,* displaying all their internal structure, which I consider a more useful and intelligible method of drawing than that of giving *regular sections.* (*a*) is a strong frame of woodwork, resting upon four legs; it has a large hole cut out in it, into which the instrument is fixed, by means of the two screws *(f f)*, in the same way that ordinary solar microscopes are to a hole in a window-shutter. The said frame is of sufficient height and width to protect an observer from the rays of the sun. It will be seen that there is considerable resemblance throughout between this instrument and the best kind of solar microscopes usually made. (*b*) is the plane mirror, made of considerably greater length than they usually are, in order *to insure a round spectrum of light from the sun when low.* (*c*) is an arm (which must be made to take off, for the convenience of packing), moving on a pin affixed to the side of the mirror, and likewise on a joint attached to a strong round wire (*e*), which slides backwards and forwards in the tube (*d*), having a spring in its interior, and a pinching screw to regulate its position. The wire (*e*) being thrust out or drawn in causes the mirror to alter its inclination, corresponding to the position of the sun; when drawn home the mirror is at an angle of 45°, (being the smallest angle which can ever be necessary under any circumstances.) The mirror has also the usual circular movement, given by an indented wheel and pinion, the thumb-screw of which is seen at (*g*). At (*h*) is placed the illuminating

GORING'S SOLAR ENGISCOPE.



J. Cleghorn, sc.

Dr. Goring, del.

lens, of one foot focus, which must not be of less than five inches diameter, and moreover, ought by all means to be made achromatic. For this purpose it will not require a piece of flint glass of that goodness indispensable to make a telescope; it will be sufficient if it is homogeneous as to specific gravity: a liquid concave lens of the sulphuret of carbon might perhaps be used with advantage. If it should be found impracticable to get glass of sufficient thickness to make a double achromatic lens of so large an aperture, two, of suitable focus, may be combined, either close together, or separated, as in the compound illuminator for opaque objects in the Amician engiscope. It is absolutely necessary that the illuminator should have *a large angular aperture,* for the *intrinsic brightness of the image of the sun formed by it will depend upon this circumstance.* If its aperture remains five inches, but its focus is lengthened say to two feet, instead of one, in order to suit the convenience of the workman, its effect will be very greatly impaired, for its illuminative power will be reduced to one quarter; because the light refracted by it, when drawn to a focus, will be found to give an image of the sun of twice the diameter of that given by the lens of one foot focus, and (the superficial contents of circles being to each other as the square of their diameters) *the original quantity of light being diluted and spread over a surface four times more extensive than when the focus was only one foot, can only have one quarter of its original intensity.* I have said this much, because it is well known that the light of a telescope with any given power is always in the ratio of the square of the aperture of its object-glass, without any regard to its angular aperture; and many persons may think that the illumination of the lens of a solar microscope, which also acts upon parallel rays, is in a like predicament. Be it known that I never have myself used an achromatic illuminator; but I have so constantly felt the want of one, that I do not scruple to recommend it as almost

as necessary to the perfection of the instrument as that the object-glasses themselves should be achromatic: for in order to get the instrument to do its best on test-objects, it is frequently necessary to cause the spectrum of the illuminator, or its focus, to fall exactly upon the object-glass; and in this case only a small portion of the middle of the spectrum is sufficiently free from colour to be used, the edges being highly prismatic; therefore, the instant the axis of the illuminator and that of the object-glass cease to coincide, either from the motion of the spectrum of the sun, or from its being thrown obliquely through the object, the whole field of view becomes full of colour, and the achromatism of the optical part is, in a certain sense, thrown away.

It may be thought by some that I have here made out rather too strong a case in favour of achromatic illumination; it is certainly a matter of taste and opinion whether it is as needful as I suppose or not, for a chromatic spectrum does not operate upon the traits of an image as a chromatic object-glass does, causing a blur or confusion in them, but merely as prismatic light would upon any other sort of picture on a white surface; that is to say, tinting it with all sorts of rainbow hues where it should appear of its natural colours; just as some of our modern artists, for the sake of effect, and more particularly to catch and strike the senses of the vulgar, daub their pictures with the most insane and ridiculous colouring, and that with no sparing hand, but with the pallet-knife itself. Such virtuosi would probably think that I am recommending rather a deterioration than an improvement on the simulachra of solar microscopes, in wishing to render them achromatic *at all points;* or, in other words, to cause them to exhibit every thing in its true and proper colours.

Indeed, I think no harm whatever, but much good, might be effected by curing the spherical as well as the chromatic aberration of the illuminator; for in this case such a conden-

sation of its light at the focal point may be expected to take place as will preclude the necessity of employing a condensing lens for the purpose of rendering the light of the illuminator still more intense and effective upon proof-objects. This is a point of great importance, for if a common uncorrected lens is used with an achromatic one for this purpose, it will greatly impair the achromatism of the marginal part of the primary one, though still, on the whole, it may do good.

The body next the illuminator is of a conical form, but has a cylindrical joint with a bayonet catch at (*l*), to receive that part of the main tube which carries the stage and the rack-work appertaining to it: this consists of a tube moving within the exterior one, by means of the rack and pinion seen at (*n m*): the end of this tube is closed, and upon it is mounted an ordinary slider-holder, (*o*,) which is fixed to its place by means of a stud passing through a niche in what may be called the stage, and turned a little way round, just upon the principle of that in the Aplanatic Engiscope, described in the "Microscopic Illustrations:" on the reverse of the stage is placed a condensing lens, of about two inches focus, and an inch and a half of aperture*, the frame of which is furnished with a sliding wire, passed through a hole in the stage formed by a piece of tube sprung at the sides in the ordinary manner,

* This condenser ought of course to be achromatic, or it will require the most unwearied attention to keep the field free from colour when it is employed (which, indeed, it is but barely possible to effect); however, I believe *it may be altogether dispensed with, if the primary illumination is achromatic.* As to those lenses usually placed at the back of the object in the ordinary solar microscope, for the purpose of enlarging the circle of light on the screen, I am happy to say I never felt the want of them with *solar engiscopes*, which is fortunate, for had they been indispensable, there would have been the same necessity for making these achromatic also as the others. If, however, it should be thought proper to retain the said field-glasses for the sake of the instrument, when converted into a solar for a room, they can of course be inserted between the plates of the slider-holder, immediately behind the object.

so that the lens may be made to swing from one side of the tube to the other, and also to approach or recede from the stage. The upper part of the tube, to which the stage is affixed, is cut away on each side, in order to permit the said lens to be moved to-and-fro. The slider-holder is made with double plates, but with two pillars only, that it may admit of a slider or glass trough of the largest size it can receive; in order that aquatic insects may be immersed in a sufficient quantity of fluid to protect them from the heat produced by the condensation of the calorific rays of the sun, and that large sliders may have sufficient space to be moved about in, &c.

The stage is also furnished with the usual apparatus for confining bodies flat to it, consisting of a pair of arms with wires attached to them, moving in sprung tubes beneath, and also with aquatic and dry live-boxes, &c. I may observe that, instead of having one tube to work within another for the purpose of adjusting the focus, the stage might be made to move upon a bar in the ordinary way, and perhaps this may be the better arrangement. It will be remarked in the drawing, that a second tube of smaller diameter, slit open at the sides, is screwed upon that in which the stage moves: this is marked *p p p*: into this again the optical part of the engiscope (*q*) is made to slide; the object-glass of which is shewn at (*k*.) The focus may of course be roughly adjusted, by sliding the body backwards and forwards in its containing tube, before it is attached to the camera (fig. 11): but when this has been done, it must of course remain immoveable. I look upon it as a *principle* in the solar microscope, that *the magnifier or object-glass should not be moved, but always remain at a fixed distance from the illuminator*; and as I have already observed, when it is intended that the illumination should be a maximum*, the focus of the illuminator should fall upon the

* If (the diameter of an object-glass being given) we wish to know what kind of an illuminating lens we should apply to it, so that the light of the picture formed should be a maximum, and bear the utmost possible

object-glass or magnifier, for then the whole of the light will be sure to pass through. If it is intended to reduce the intensity of the illumination, then the magnifier, &c. should be placed within the focus according to circumstances, and any portions of the edges of the spectrum may thus be cut off at pleasure.

If the tube (*p p p*) is unscrewed and removed, another appropriate mounting may be used in place of it, and to this the various object-glasses may be affixed without the body or eye-glasses. The instrument then becomes a solar microscope of superior construction, and the image may be thrown upon the wall of an apartment, the whole apparatus being of course removed from the frame (*a*), and attached to a window-shutter in the usual way, and the room darkened.

In the case of the engiscope, however, the end of the body (*q*) is pushed into its receiver at (*r*, fig. 2), which communicates with a conical tube of brass, having a rectangular prism with its reflecting side silvered, or a plane metal adjusted at its head (*s*), so as to throw down the image to the bottom of the box or camera, where it is to be received on paper, or on a surface of plaster of Paris duly curved to suit its shape. The camera is constructed with windows (*v v*), so as to admit two persons to look at a time, and might also be made for three;

amplification, we have only to *select a lens which shall form an image of the sun of the same diameter as the object-glass, and give it the largest angle of aperture posible*; or if a condenser is employed, we may use a lens of long focus and large aperture in the first instance, and condense the image of the sun by a smaller one into the required compass. I should apprehend that an illuminator of twelve inches aperture, and two feet focus, would, as a single glass, give a *maximum* of light with the lower powers used in common solar microscopes; for the higher ones a condenser would be necessary, to enable the whole body of light to clear the small apertures of the object-glasses, and proceed to the picture.

We may draw the following inference from what has been here explained, viz. *that it would be very easy to make a solar instrument on a gigantic scale with an illuminator of enormous actual aperture, which, nevertheless, would have no more light or intrinsic brightness in its image than a much smaller one, scientifically made.*

but I am afraid this would cause the eyes of the observers to be somewhat too far off from the image to see its minutiæ with sufficient exactness; (*w w*) are two pieces of wood carved out to fill the slope of the upper part of the face; one is represented in a plan separately (at 4) in which the aperture (*y*) is seen, and that part of the block which closes round the nose. I have found it necessary to exclude the breath from entering the camera, as it dims the eye-glass of the engiscope, and thus spoils the image.

The sides of the said camera (*u u*) are made to remove at pleasure, to permit the observer to draw the image; some black drapery being hung on in place of the sides, to exclude extraneous light, while the hand is admitted through a cuff made in it. The legs of the camera (*x x*) are made to unscrew at pleasure, others of greater length being used in lieu of them, when it is necessary to elevate the head of the camera to the height of the body of the engiscope when equipped with the opaque box; but blocks of wood with holes in them may of course also be used for the same purpose. The whole of the exterior of the conical brass tube and camera should be well blacked, or lined with black silk velvet. And the totality of the apparatus of the solar engiscope should be placed on a very firm solid table, in an apartment on a ground floor, in a situation where the tremor occasioned by the passing of carriages, &c. cannot be felt.

Fig. III.

Is the opaque apparatus of the solar engiscope, differing but little from that commonly made; when used, it applies to the conical part of the body shown in Fig. 1, by means of the bayonet catch at (*l*), as the transparent apparatus did; (*r*) is a plane mirror governed by the adjusting screw (*s*), to throw up the light of the illuminator to the object (*o*), which is adapted to the focus of the object-glass (*k*), by means of the adjusting

screw (*t m*), which causes the stage which carries the object to move backwards and forwards in a socket, framed in the back of the opaque box. However, I believe it will be found that with such powers as can be used to give images of opaque objects, no adjusting screw will be necessary, for the object may be pushed to-and-fro with the finger with sufficient exactness. The stage is formed by a piece of cork covered with black velvet, to which insects may be fastened by means of the pins used to keep them in their Cabinets; as may also other objects similarly mounted, viz., on corks having pins passed *diagonally* through them: discs also of blackened wood may be made to fit into the stage, in place of the cork one, for receiving insects; and a sort of stage will be found very useful which merely consists of a little round shelf placed rather below the axis of the optical part; on this any thing may be laid for exhibition.

I have supposed the little door of the opaque box to be removed in the drawing, or to be transparent, in order to let the apparatus be seen.

(*p p p*) is merely the tube into which the body of the engiscope (*q*) is inserted as before. It may be removed, and a simple object-glass affixed in an appropriate mounting (at *m*); the instrument then becomes a solar opaque microscope, and is managed as such.

METHOD OF MANAGEMENT—EXHIBITION OF TEST OBJECTS, &c.

It will be remarked, that the necessary directions for managing the instrument are mixed up with the description of its various parts: I think, therefore, little more need to be said, except a few remarks on the exhibition of transparent proof-objects, for little can be done in the way of shewing opaque ones.

The management of the illumination is, perhaps, more easy

in the solar engiscope than in any other; for the light of the sun seems to have the power of bringing out all the lines and markings in tests when thrown perfectly *direct* through the axis, or, where this does not happen to be exactly the case, the natural motion of the sun, if left to itself, soon renders the illumination oblique, and *if the lines happen to be in a proper disposition with respect to it,* brings them out as a matter of course. The line in which the light travels may always be discovered by putting the object out of focus, according to the directions I have given for the management of proof-objects in the Amician catadioptric engiscope; and by turning the slider about, the lines of some of the scales may always be placed at right angles to the direction of the rays For this purpose, however, it will be advisable that the slider should be very short, and have only one hole in it, otherwise there will not be room for it to turn round in the tube (*i*). The condensing lens behind the stage being moved a little on one side, also gives oblique light.

When an object-glass of rather long focus is used, say of two inches, which is a very pleasing magnifier for ordinary objects, the slider-holder should be removed, the object or slide laid flat against the stage, and confined to it by means of its arms; because, in this case, the object-glass may still remain nearly in the focus of the illuminator, which will be at one foot distant from it: if, on the other hand, the body of the engiscope is drawn farther out to adapt itself to the slider-holder, a great loss of light will be the consequence, because the rays from the illuminator will have begun to diverge before they reach the object-glass.

I have frequently been surprised at the great condensation of the solar rays to which the transparent proofs may be exposed, without burning or apparently affecting them in any degree. I have in the winter, when the sun was low, condensed the whole of the light furnished by the illuminator of five inches aperture and one foot focus, by the other behind

the stage of about two inches focus; and *very nearly* in the focus of the latter I have kept the podura for half an hour together, which seemed to resist its action just as cobwebs will do, being, I suppose (like cobwebs) too fine and delicate to arrest a sufficient portion of the calorific rays of the sun to produce combustion. I do not recollect ever burning a transparent proof-object, though I have the slider which held it: but I hardly ever began to exhibit opaque objects without meeting with some accident of the sort;—they can seldom be well shewn without being placed in jeopardy; for it seems to be necessary, in order to get a good picture of these bodies, that *the focus of the illuminator should fall exactly upon them:* it will not answer to place them either within or without the focus, for the purpose of securing them against the danger of combustion; we must, therefore, ascertain, *à priori,* what degree of heat the object we are about to exhibit will be likely to endure, and adapt that of the spectrum to it, by cutting off some of the aperture of the main illuminator, by means of rings of pasteboard placed between it and the mirror. It may sometimes also be advisable to have recourse to the same expedient with transparent bodies, instead of placing them within the focus; and it is, perhaps, the more scientific mode of proceeding of the two, though in the latter case both may be had recourse to. It would, however, be still better to have a spare achromatic illuminator, of the same aperture, but twice the focal length of the other, with an extra joint adapted to lengthen the body, when it was used either on very inflammable opaque objects, or in very hot weather, or in a hot climate, on delicate transparent ones.

With good object glasses of short focus and large angular aperture, of from 1-10th to 1-18th of an inch focus, and about 55° of aperture, a picture of all the markings on the podura may be distinctly exhibited, and likewise the longitudinal lines and their cross striæ on the brassica; *but I have never yet seen a picture of the diagonal lines on the latter,* though I

do not altogether despair of doing so. I have carefully studied the pictures formed by deep achromatic triplet object-glasses acting with Huyghenian eye-pieces, and when the said object-glasses were really good, have found their images, *according to my own taste* in such matters, better finished and more perfect than those given by common doublets and triplets of equivalent power. The latter, however, perform very well also, and give the more luminous image of the two; and so will also single magnifiers. I have tried against each other a very fine 1-60th of an inch lens of glass, (equi-convex,) a doublet of 1-70th, and a triplet of 1-50th, and excepting the difference in the size of the image, could not say that I perceived any sensible superiority in either. The engiscope I have mentioned with the object-glass of 1-18th inch focus, though its light was inferior charged with the same powers, *by its mere achromatism instantly effected a great improvement in the picture for the better;* it moreover resolved several of the scales of the podura which the doublets and triplets did not, and shewed the cross striæ on the brassica in a much more decided manner than they did; the said objective, notwithstanding, was far from being a perfect glass, having a considerable quantity of uncorrected aberration of the convex kind, and rather too short a focus to be achromatic.

REFLECTING SOLAR ENGISCOPE.

It is obvious that a reflecting solar engiscope on the Amician principle may very easily be constructed, by applying the body and bar of the catadrioptric instrument, described already in this work, to the top of the camera (fig. 2) in lieu of the conical brass tube, the illuminating apparatus remaining as before, and the aperture in the side of the tube containing the metals being posited precisely where the object-glass of

the refractor is, or, more strictly speaking, where a single object-glass would be, if the instrument was in action as an ordinary solar; I have used an instrument made precisely in this way, only the body and bar were not attached in any way to the illuminating apparatus, but only adjusted so as to coincide well with it. It thus makes a very pleasing instrument; but will only shew the most easy lined objects, from want of power in the objective part, which, as it is well known, cannot be made of less than 3-10ths of an inch focal length, for it requires a *very great depth and power* in an object-glass, or metal, as well as a very considerable degree of perfection, to *render the niceties of proof-objects visible in a picture formed of them;* moreover, the reflecting engiscope is well known to be much darker than an achromatic instrument of equivalent power and angular aperture; and there is another unfortunate circumstance attached to it (the reflector) when used as a solar engiscope, viz.'*the hole in the side of the tube, which is always much smaller than the object metal*; for in order that the illumination should be a maximum, *the spectrum of the illuminating lens must fall upon this hole, and clear it,* as it does the object-glass in the refractors, which are of course of much larger diameter than the said hole, and therefore can admit a much greater quantity of light.

Opaque objects can hardly be depicted at all by the reflector; and as the metals of long focus are usually made of small angles of aperture, merely to create space between the sides of their containing tubes, for the purpose of illuminating opaque bodies, it would be advisable if a regular reflecting engiscope was tried to make them with as large *angles* of aperture as possible, because they can, in the said instrument, only operate on diaphonous subjects: thus, that of two inches focus should have an inch at least of aperture, instead of half an inch; that of an inch focus, half an inch, and so on, in order to gain as much light as possible. After all that could

be done, however, I am afraid a refractor would be sure to beat it hollow*; therefore I shall take my leave of the subject, as I cannot conscientiously recommend such an instrument.

OXY-HYDROGEN ENGISCOPES.

These instruments are constructed by applying the optical part of an achromatic engiscope, with the camera already described, in lieu of the magnifiers and screen used with the ordinary oxy-hydrogen microscope; but retaining the illuminating and other apparatus belonging to the latter instrument: in short, the construction must be so obvious to the artist, that I conceive it perfectly superfluous to say any thing farther on the subject. Whatever advantages are possessed by solar engiscopes over solar microscopes, will, in like manner, be retained by oxy-hydrogen engiscopes, or oxy-hydrogen microscopes; *but there is a milkiness, or want of serenity and clearness,* in the light produced by the action of the oxy-hydrogen blowpipe on lime, which renders it very inferior, in the exhibition of the superior order of tests, to that of the sun. How, indeed, can we expect it should be otherwise? I am afraid this would still be the case if the light of the lime could be rendered as intense and brilliant as that of the great luminary at his proper distance from us.

Much has been said about the superiority of the hydro-oxy instruments, in enabling us to dispense with the uncertain sun of our northern climates, and about solar microscopes requiring our confinement during the finest part of the day, &c.;

* A friend of mine, who was perfectly qualified to make such experiments, assured me that he had constructed a solar microscope, with metals on the Amician principle, used *without a body or eye-glasses,* and exhibiting an image in the usual way on the wall of an apartment, and found that it exhibited a variety of test objects in a highly satisfactory manner. I have myself never tried the metals in this way.

but we must not forget that in *warm climates* the light of the sun is nearly certain for months together; and so fiercely is shed "the intolerable day," that we are kept at home under penalty of a knock on the head from this mighty body. Under these circumstances, more especially where every puddle swarms with life, and the whole atmosphere with the most brilliant and curious insects, I humbly think a solar microscope or engiscope, managed by a couple of slaves, who might easily be trained to exhibit it, would have as many charms as a siesta; unless, indeed, the heat should prove so oppressive as to incapacitate us for all rational amusement, and compel us to sleep, whether we will or not. People cannot have their cake, and eat it too; and if they will sleep by day, they must lay awake at night; I therefore recommend the inhabitants of warm regions, whether black, brown, whitey brown, toad-coloured, red, yellow, or white, to betake themselves to these instruments, and try their effect in killing time during the heat of the day, in conjunction, of course, with cards, hookahs, dancing girls, &c. &c., and never to forget their obligations to me for suggesting to them a new species of pleasure.

C. R. G.

CHAPTER V.

ON TRYING

MICROSCOPES AND ENGISCOPES

AGAINST EACH OTHER;

WITH RULES FOR ASCERTAINING THEIR COMPARATIVE MERITS.

Trying instruments against each other may be thought a mighty simple affair, and that very little can be said or written with propriety on such a subject. As much may be asserted of running horses against each other: nevertheless, horse-racing has its rules and regulations, established by the joint consent of the sporting world, many of whose ordinances may appear at first sight not a little unjust and absurd. Thus, that two horses matched against each other should not carry equal weights on account of a difference in their age, and that such weight shall be determined by a scale nearly or altogether arbitrary; that a horse shall be considered beat because his opponent happened to come in first by *some small fraction of the length of his head;* or that the most trifling loss of weight in the rider, such as that of his whip, shall cause the horse to lose, though he was to distance his adversary by a hundred yards at the goal, and the like, certainly must be considered very vexatious laws; and though they are as fair for one person as another, it may be truly said they are fair for nobody. However, when such consequences attend the loss or winning of a race as the loss of perhaps twenty or thirty

thousand pounds, and the utter ruin of one man to the making of the fortune of the other, it is evidently necessary that the most minute circumstances should be taken into consideration, and that every possible contingency should be determined in some way or other, so as to place the matter beyond controversy or appeal, or every race-course would present nothing but a scene of angry contention, and of quarrels which only an appeal to arms would settle.

Now let us suppose that a couple of microscopists were to pit their microscopes or engiscopes against each other, to shew some particular proof object; and in order to increase the interest of the trial, should bet sums of money on the event; how, and in what manner, are we to determine which instrument shews the said object best, and which of the parties is to lose his money on the occasion? We cannot for a moment suppose that either of the parties will have such excessive candour and complacency as to give up the point when it should be given up: no, every man is almost sure to make an idol of *his own* instrument, be it what it may. If the case resolves itself into *a matter of opinion*, one man's is at least as good as another's; and an ounce of a man's own wisdom is always worth a tun of his neighbours. Is it not most notorious that all *savans*, inventors, and projectors, have, time immemorial, regularly puffed their own productions, and decried every thing else with scarcely a grain of candour? The most trifling mote in the works of others they can see, and expose and magnify; but they cannot and will not see the beams in their own.

Under all these circumstances I think we must begin by laying it down as a rule that no man's judgment is worth a straw, relative to *his own instrument,* even in a case where there is no money to be lost or won by it. In the case proposed above it would be necessary to appoint two indifferent persons as judges; and if they cannot agree, to refer the matter to a third, as umpire, whose judgment should be final,

and without appeal. If it should be asked, of what description should such persons be—should they be profound opticians or microscopists?—I should answer, that any individuals whose sight is perfect are competent to the task; the more so, perhaps, if they never looked into a microscope in their lives, for then they are likely to be without prejudices of any kind. I was myself, when I first began to reform microscopes, very much in the habit of taking the opinion of *an actress* on them; and her decisions were anything but agreeable to me, though I believe they were perfectly correct. Whatever objections there may be to the owners or inventors of particular instruments being allowed to have any voice in determining their specific merits, they are the most proper persons in the world to have the management of them, as they will be sure to display their powers and properties to the greatest advantage, and make them so put forth their whole mettle as certainly as a man will who rides his own horse, and has betted money in his favour on the race-course: therefore it is not necessary for the judges to understand a tittle of the method of managing microscopes or engiscopes, all of which is to be left to the commanders of them: the said judges have nothing to do but to look at the object when duly prepared for their scrutiny.

Having pitched upon judges, it remains for us to ascertain by what laws they shall be governed in their decisions; for it is impossible to give a sound judgment in any case without reference to certain principles; even a common game at cards cannot be lost or won but according to certain rules.

I shall lay down what I consider the laws by which microscopes and engiscopes ought to be judged beaten or victorious; they who do not relish them can establish others, which they may consider more equitable; for laws there must be, of some kind or other, before we can proceed a step in our decisions.

SECTION I.

CODE.

Art. 1.—That instrument is the best which shews the different details of objects most decidedly, and with the greatest clearness and perspicuity*; no matter of what nature or kind, or whether it is chromatic or achromatic, planatic or aplanatic, in or out of adjustment, or whether its lenses are well or ill

* The capability of counting accurately the number of any particular traits or objects, developed both in telescopes and microscopes, has been adduced as decided evidence of the goodness of these instruments, and their power of shewing things in a *decided and forcible manner*. I know not exactly how the truth may be; of this I am certain, that I have seen objects as I should say with the very *intensiva of distinctness*, and yet I am quite confident I could not have counted them truly: perhaps I have not acquired the habit of doing so, or may have some natural incapacity on the subject; for I have frequently found myself unable to count aright the number of sheep in a meadow, when not amounting to more than threescore. I have heard graziers assert that considerable practice is necessary in order to be able to count sheep and herds of cattle accurately.

With respect to lined objects, I have, in the "Microscopic Cabinet," p. 179, given it as my opinion, that they are seen to the greatest advantage, and in the most perfect style, when the spaces between the lines are clear, and the lines themselves dark and strong, as if drawn with a pen and ink on white paper. When scales and feathers are exhibited as opaque bodies—for example, a scale of the diamond beetle—with a high power, the lenses should appear as furrows, or with distinct ridges, dark one side and light on the other, as a ploughed field seen when the sun is low in the horizon, and its beams play across the furrows. Where several systems of faint lines cross each other *in an irregular manner*, the result will be an appearance similar to the watering of silks and moreens. This may be verified by applying two wire sieves, or two pieces of worsted gauze, to each other, and holding them up to the light. The markings on some scales of the podura seem to be of this description; others seem mere points, arranged so as at first sight to give the appearance of a system of lines, or of two crossing each other. The studs on the skin of a boiled pullet, seen as opaque bodies, removed to some distance from the eye, are not an inapt illustration of this sort of optical deception; those of the feathers near the pinions, in particular.

There is certainly a very great difference in the degree of facility with which different specimens of the podura may be resolved into lines, as

worked, or polished, or centered. If a microscope made out of the lens in the eye of a stinking whiting *would shew me something which I could not see with any other**, I should say it was the best, and had beaten every thing else out of the field.

Art. 2.—*The same identical object* must be applied to each microscope and engiscope, tried against each other: supposing the objects to be the scales of insects, a drawing must be made of the configuration of them, that we may be able always to pitch upon one particular specimen.

Art. 3.—Cæteris paribus, I should say, *that instrument which will shew an object perfectly with the lowest power is the best:* thus if one instrument, A, shews an object distinctly and satisfactorily with a power of 200, while another, B, will shew all its minutiæ equally well, though *on a smaller scale*, with 100, I should say that B was the best: in this case I suppose that when the power of each is made equal to 100, the performance of both is not equal, but that B has the advantage. But if the power of each was raised to 200, and then A had the advantage, I should still say that B was the best. I have often insisted on this point in my writings, and assigned what I consider sufficient reasons for my assertions.

well as in the strength and plainness of their markings. A curious phenomenon sometimes presents itself in some choice pet scales, having straight lines from end to end, and two systems of oblique lines also, both apparently grooved in a decided manner, as is the case with many I have seen; viz. one of these systems may be seen by looking *directly*, and the other, *without any alteration in the illumination*, by looking *obliquely* into the instrument. The same circumstance occurs with some other tests.

* There is a very ordinary object, which I can never see with any instrument, which certainly we should expect to be visible by mere magnifying power, with the common microscope;—I allude to the edge of a very sharp razor, presented to the axis in a line bisecting the thickness of the back, so that the thickness of the said edge, or its apex, should be truly shewn and measured, as it may be in a dull case-knife. I suspect the edge of a very sharp razor is the nearest approach to a *mathematical line* with which we are acquainted; it seems to resist magnifying power altogether, or at least such as we can apply to it.

Art. 4.—If two instruments, C and D, shew the lines and markings on an object equally well; but C shews the edge of the scale or feather with the same adjustment of the focus which serves best to bring out the lines, so that the outline and the lines are simultaneously visible, and D does not; then C is the best.

Art. 5.—If one instrument shews the lines on any particular test as if composed of an aggregation of dots or globules; or exhibits them broken, interrupted, and ragged, while another shews them clearly made out, as veritable lines or stripes drawn with a pen and ink; the latter is the best. In the first paper I wrote on test objects, I have given as many as five degrees of illusive or false vision produced in the appearance of the feather of the *Morpho Meneläus,* by viewing them with an object-glass deficient in defining and penetrating power.—*Vide* Quarterly Journal, Vol. xxii. p. 265*.

Art. 6.—If two instruments shew certain lined objects *as transparent bodies* equally well in all respects, but one will shew them more or less evidently *as opaque objects* also, while the other will not, then it has clearly the advantage over the other.

N.B.—One of the best methods of exhibiting scales as opaque bodies is to take away the disc of talc next the eye, replacing the ring; and then to attach a black wafer, or a bit of black paper, to the reverse of the remaining piece of talc, to which some of the scales will generally adhere. In this case I have supposed the scales under consideration to have been mounted in the ordinary way, in slides or circlets, as transparent bodies; and that we wish to be sure of seeing some of the same scales we have seen as transparent bodies, as opaque ones also. If the upper piece of talc is allowed to remain, it will prove a considerable detriment to vision; but still it will be as unfavourable to one instrument as to another.

* See also "Illustrations of the Effects of Aperture," &c. &c. in this work.

Art. 7.—If two instruments should prove equal in all other respects, but one is achromatic and the other not, that which is achromatic has of course the advantage, as it will shew the objects perfectly free from false colouring.

Art. 8.—If two instruments seem to shew transparent bodies equally well, but one of them, when tried upon opaque ones, has a slight fog of the diffused kind over its whole field, or a penumbra or nebulosity encircling numerous points, to a certain distance from them, while the other is free from this illusion, that which shews the opaque objects best is the winner, for opaque objects are still more severe tests than transparent ones.

Art. 9.—Whenever one instrument happens to shew some marking or feature in an object not visible in another, and the owner of the latter attempts to get rid of this, by asserting that it is an illusion produced by some defect of his antagonist's instrument, let him be made to *prove* his assertion to the satisfaction of the judges, or the umpire; and if he cannot do so, let him be turned adrift as a scamp and blacklegs. Let us suppose, for example, that the trial was the wheel animalcule *(vorticella rotatoria)*; and that in the instrument said to exhibit an illusion two points were visible near the head of the animal, when in its grub form, with the wheels withdrawn, (supposed by some naturalists to be the eyes of the animalcule) I should say that the *illusion* here was in the instrument, which *did not shew them;* for a false evidence may be given by suppressing facts, as well as by coining false ones.

There are several minor points which might be insisted upon; such as that instruments which have a strong natural light, combined with a large field of view, free from distortion, and equally good all over, have the advantage over such as cannot pretend to these properties; but as such instruments no not seem to possess any absolute power of *shewing anything more or better* than others, I shall lay small stress on these properties.

When we wish to ascertain which instrument is most perfect in point of *figure*, *achromatism*, or *adjustment*, &c. I have laid down abundant rules for this purpose in Chap. XIX. of the "Microscopic Cabinet," and shall merely therefore remark, that if we wish to ascertain which instrument is constructed on the *best principle*, and what kind of microscopes or engiscopes are made on the most effective plan, in this case the instruments to be tried against each other should have their object-glasses or metals of exactly the same angular aperture and focus; their bodies also should be of the same length, and their eye-glasses of the same nature, description, and magnifying power. When doublets, or triplets, or single magnifiers, are tried against each other, their power and angular aperture must also be scrupulously equalized; or if they are tried against engiscopes, their power and aperture must also be made equal to theirs.

In my paper in the "Microscopic Cabinet," page 202, line 22, nearly a whole paragraph is wanting; which unfortunately changes the sense of the context, and makes it read very ill. This being part and parcel of my present subject, I shall here introduce, as well as I can, from memory, not having the manuscript by me.

"It must however be recollected that single and compound magnifiers, the diameters of which exceed that of the iris of the eye, for the time being, cannot have their aberrations, either chromatic or spherical, estimated in the manner detailed above; because the said iris, or moveable curtain, of the eye, cuts off their aperture to its own standard, so that only *a certain central portion of them*, equal to it in diameter, can be tried. When their foci are too short to be tried on opaque objects, their defects and aberrations may be looked into by viewing the penumbra of transparent objects put out of focus; or rather the penumbra of some body which is not transparent by intercepted light proceeding from behind it." Then should follow the concluding sentence of the paragraph.

Since writing the paper I have alluded to, in the "Cabinet," I have discovered an object which will be found very useful as a test of aberration, when the focus of an object-glass, or of a single or compound magnifier, is too short to allow us to see a globule of quicksilver with it as an opaque body.

Stick two pieces of talc together with a little Canada balsam, in such a manner as to include some small globules of air between the plates; this will be very easily effected: when these are viewed by intercepted light, they appear as *very small discs perfectly black, having a luminous point in the centre,* which has almost the appearance of an artificial star, only not so bright: by putting this within and without the focus (always taking care that the illumination, which should be daylight, is reflected by a plane mirror, is thrown *directly through* it, otherwise the luminous spot will not be centrical), the state of an object-glass or magnifier, as to chromatic and spherical aberration, adjustment, and centricity, &c. can be as well looked into as by a globule of quicksilver, and the pretensions of different constructions scrutinized and brought to the grindstone.

Another object of a similar nature can be produced by mixing together some oil and water in an aquatic box, and agitating the two fluids until the water is dispersed into very minute globules, surrounded by the oil; in this state they closely resemble the air bubbles, surrounded by the balsam.

SECTION II.

It will probably be expected by the public that I shall now take upon me the disagreeable and invidious task of favouring the world with my own particular notions of the comparative merits of the different sorts of microscopes and engiscopes; an

office which I am afraid I shall execute to the satisfaction of no one human being, while I shall be certain of putting the noses of a great many completely out of joint: I would as soon undertake to give a comparative estimate of the beauties and perfections of a dozen different women, to the satisfaction of the ladies themselves and their lovers. I really think I have gone far enough in laying down a code of laws on the subject, which others may put in execution, (at least if they like.) If, however, I may be permitted to proceed to judgment, according to my own code, I will endeavour to do so: I will not hazard any mere opinions, if I can help it, but merely *state facts, and draw (if possible) legitimate inferences from them*; and if they should happen to be at variance with statements heretofore published by me, I request my reader to consider those now to be given by me as my *most mature conclusions, revised and corrected,* with the whole attention of which my mind is capable, according to the most recent improvements in the different instruments. Though, as I have already asserted, there is no microscopist living who may be expected to give a perfect and absolutely unbiassed criticism on the matter in question, yet I may be as well qualified for the task as most others; for I have been principally concerned from the very beginning in carrying into effect the various reforms in the structure of instruments which have made them what they now are, and may therefore regard them all with equal favour. If I have never interested myself much about compound magnifiers, it was because I conceived that a very great man had taken up the subject before me, and exhausted it, leaving opticians nothing to do in the branch, but to carry his theories and combinations into effect to this best of their ability.

As the subject is one on which much stress is laid by many, I shall here take into consideration the comparative illuminative power, or intrinsic brightness, or light, of various instruments; though I think it will be found in the sequel not to merit much attention, as far as microscopes are concerned.

If we take a piece of any well-polished plane glass, placing a piece of black velvet, or some other dark substance, behind it, to prevent the image from being confused with the rays which it refracts from surrounding objects—or, what is still better, a piece of black glass, having the same reflecting power as the white, and view the picture which it forms of a landscape, or any thing else reflected, as nearly as possible at *right angles* by it—we shall be surprised at the quantity of light arrested by a single surface only, for in the image may be distinctly recognized every object seen in the landscape by the eye, together with its colour; only every thing is a vast deal darker than in nature, the difference being apparently about as great as the light of a twilight evening is to that of meridian day. Now, when we reflect that every polished glass surface reflects an equal quantity of light, we may wonder how we see objects at all in an instrument composed of many glasses, and may be very much inclined to think that the fewer glasses we see through, the more perfect must be our vision; that, in short, single lenses must inevitably be the best instruments after all; and such was the opinion of Leeuwenhoek and all the early microscopists. Lenses formed of gem, especially diamond, must be much darker than glass ones, from the greater reflective power of such substances, which defect, however, ought (if there be any truth in analysis) to be much more than compensated for by their high refractive and low dispersive power. Jewelled simple microscopes, then, (*à priori* at least), should seem, upon the whole, to stand upon the top of the scale; but as we here only consider *illuminative power*, they certainly occupy only the second rank, or, if coloured, as is the case with many of them (sapphire and garnets, for example), a still lower one. Doublets must of course arrest twice as much, and triplets three times as much light as single lenses formed of the same glass; and an engiscope, consisting of four, five, or six glasses, &c. four, five, or six times as much, under any given illumination.

The question of the comparative light of reflecting and refracting instruments has been often agitated, and generally determined in a very unfair way by the champions on both sides. The amateurs and makers of refractors, led away by their hatred and contempt of the reflecting tribe, have gone the length of asserting that an achromatic engiscope, having a sextuple, or two triple object-glasses, has fully four times as much light as a reflector of the Amician construction, having the same power and angular aperture; and that another having an octuple object-glass, composed of four double achromatics not cemented together, has still more light, *cæteris paribus*, than the sextuple one*; a quantity of light being, I suppose, gained, *not lost*, by the refractions of the two extra glasses. I merely quote these opinions to shew to what lengths a bigotted zeal for any particular kind of instrument may carry even very clever opticians. The opposite faction, exasperated at the quantity of dirt and calumny thrown in their teeth, will naturally take up the cudgels for their darling principle, and retort in the same style upon the imperfections and blindness of the refractors, until the affair becomes a contention for victory instead of truth.

Let us see if there is no way of determining this question in a natural and philosophic manner.

The late Mr. Charles Tulley, of Islington, (whose like we shall not see again in a hurry, and than whom I never met with a more candid, gentlemanly, and scientific optician, ever ready to do justice to every thing and every body), assured me that he had been at great pains, and made many experiments, to determine the comparative light of reflectors and refractors, the results of which I shall state. His favourite method of experimenting (and I do not see how a better or fairer can be employed), was to charge a reflector and a refractor with the same power, and to direct both to a printed bill, placed at an

* A discovery of the late Mr. W. Tulley.

equal distance from each, on a clear evening; and as the light gradually diminished, to see how long he could read it in each: in an instrument whose light or penetrating power was superior to the other, he could distinguish the letters long after the other had become too dark to permit him to do so: but where the light of both was equal, or made so by reducing the aperture of the brighter one, the power of reading in both faded away at the same time as the twilight gradually deepened.

After many trials made by himself in company with other persons, he arrived at the conclusion, that a refractor having a double object-glass of five inches aperture had as much light as a reflector of the Newtonian construction of eight inches aperture, *cæteris paribus;* and the light being in the ratio of the *square of the apertures* was therefore as 25 to 64. Thus, where the apertures of a reflector and refractor are equal, the light of the former is represented by 25, that of the latter by 64: or it may be expressed thus,—the light of the reflector is to that of the refractor as 1 to $2\frac{14}{25}$. Now, it can scarcely be necessary for me to observe, that the Amician catadioptric engiscope is a Newtonian telescope, made on a very small scale, reversed, and that its light must therefore be the same, with this difference, that the diagonal metal being much larger than in the Newtonian, arrests much more light. Its proportional diameter varies in the Amician in different sets of metals, and with it the size of the blot in the middle of the visual pencil. In the pair of 55° of aperture, and in that of 13°, it is one-third of the diameter of the elliptic one; but in that of 36°, one-half. Mr. Cuthbert has sometimes made metals of 41° of aperture, with a *focus beyond the tube;* in such the size of the small metal is necessarily increased, so much as to leave only the mere margin of the concave in operation: on this account they are very dark indeed, as much so as their worst enemies can wish; but metals of this aperture ought always to be made on the same plan as those of 55°, in which the slider is passed

through the tube, because in this construction the size of the diagonal can be kept somewhat under a third of that of the elliptic one.

I have thought it right to allude to these circumstances, because many would think it perfectly correct to pitch upon such a pair of metals as I have described, as a fair specimen of the whole. "*Ab uno disce omnes.*."

In the Newtonian telescope the diameter of the diagonal is generally one-seventh of the other: thus, in one of seven inches aperture the plane is one inch; it therefore only arrests 1-49th part of the whole light, and this is of course considered in Mr. C. Tulley's estimate aforesaid; and if we want to know how much darker the Amician engiscope is than the Newtonian telescope, we have only to calculate *how much more light is arrested by the diagonal in the one case than in the other.* Now where the plane is 1-3d of the diameter of the concave, it arrests 1-9th of the whole; but in the extreme case, where it is one half, it stops one quarter: therefore, where the light of a Newtonian is rated at 25, the light of the Amician will in the first case be represented by $22\frac{2}{9}$, and in the latter by $18\frac{3}{4}$. But in order to obtain the light of the Amician, we must deduct the 1-49th from the 1-9th and 1-4th of the light stopped by the diagonals of the engiscope, and the account will stand thus:—

$$\frac{1}{9} - \frac{1}{49} = \frac{40}{441}$$

$$\frac{1}{4} - \frac{1}{49} = \frac{45}{196}$$

Therefore $\frac{40}{441}$ of $\frac{25}{1} = 2\frac{118}{441}$ deducted from 25, leaving $22\frac{323}{441}$, represents the light of an Amician in an *ordinary case,* compared with a refractor of the same aperture having its light estimated at 64; and $\frac{45}{196}$ of $\frac{25}{1} = 5\frac{145}{196}$, deducted

from 25, leaving a residue of $19\frac{15}{196}$, represents its light in an *extreme* case. Now if we compare the aforesaid numbers against 64, the representative of the light of the refractor, the results are, that the light of the reflector in an ordinary case, compared with that of a refractor, is as 1 to $2\frac{176}{200}$; in an extreme one, as 1 to $3\frac{119}{3775}$: and be it remembered, this is when it is compared with a refractor consisting only of ONE DOUBLE OBJECT GLASS; but there is a confounded deal of difference between the light stopped by four surfaces and that arrested by twelve or sixteen, as will soon be discovered by any one who experiments fairly; and even when an object-glass consists of two or three double ones, with their inner surfaces cemented together, there is still a loss of light to a very considerable extent beyond that occasioned by one uncemented double one*.

They who think I have not darkened the reflector sufficiently can experiment for themselves, by trying refractors and reflectors against each other in a clear evening, taking care to place the instruments in the same aspect, so that the light whereby they are illuminated shall come from the same part of the sky which is always darkest at the zenith, and lightest in the west, low down in the horizon, where a rich saffron tint

* According to the calculations and experiments of Sir W. Herschel, in his paper "*On the Power of penetrating into Space by Telescopes, &c.*"—(*Phil. Trans.* for 1800, p. 65,) out of 100,000 incident rays, 94,825 only will be transmitted through a lens of glass of the ordinary thickness; hence if two lenses are combined, only 89,918, which, subtracted from 100,000, leaves 11,082, the quantity which will be arrested by every double object-glass, being somewhat more than *one-ninth part* of the whole of the incidental light: therefore we must deduct 1-9th for the light lost by every additional double glass employed, which is a quantity equal to the whole stopped by the small metal ofthe Amician, under order ordinary circumstances. Sir W. calculates, that where a double reflection takes place *at right angles*, as in the Gregorian telescope, out of 100,000 rays, only 45,242 will be reverberated, a loss of more than the half. This statement agrees tolerably well with that of Mr. C. Tulley, but makes the reflectors rather more luminous than he does.

frequently remains for a long time after sunset. *No illuminating lenses or mirrors must be used;* the object-glasses or metals must be directed to the same point of the heavens, and the natural light of the atmosphere uncondensed and unaltered by either refraction or reflection, the sole illumination used. If these conditions are not fulfilled, the experiments made will be good for nothing, as must be evident.

For my own part I consider the question of the comparative light of reflecting and refracting microscopes and engiscopes not worth agitating; and I think the following experiment quite conclusive on the subject:—Take an Amician, equipped with one of its darkest sets of metals and its deepest eye-glass; mount it for viewing some transparent test, or at least something or another requiring great distinctness for its manifestation; illuminate it by reflecting the light of the sky from its plane mirror (an operation which of course reduces the light), and you will find *that dark as the instrument is, it is more luminous than consists with perfect distinctness,* and that you may greatly improve the vision by using diaphragms under the stage, *reducing the light of the field several shades lower.* Again, opaque objects we can brighten at pleasure, by compound illuminators, and lamps fed by oxygen gas, &c. &c.

In telescopes the case is totally different, any defalcation of *their* light being sure to be attended with a serious defect in their performance upon all objects requiring penetrating power, because we have no means whatever of increasing their intrinsic brightness.

It will be found that *a certain angle of aperture in metal is quite equal to the same aperture in glass,* as to its penetrating power in developing the tissue of all sorts of lined or proof objects, when aided by a proper illumination; and I need not say, that with respect to telescopes, such a position is entirely false: therefore there is a wide difference between the relation of the refracting and reflecting principles to each other, when applied to these different instruments; and *the performance of*

*reflecting engiscopes is proportionally far superior to that of reflecting telescopes,** though it is most fully admitted that their natural light or intrinsic brightness is greatly inferior to them. The worst point about reflecting engiscopes, in my opinion, is, not their darkness, but the *brownness* of their light: this is very perceptible in reflecting telescopes also, when used with high powers, and is in both instruments remedied to a certain extent, by using eye-glasses of crown glass instead of plate.

In the Amician, used with day-light, it causes objects, or rather their images, to appear just as if they were depicted on *brown academy paper*; and the effect is very disagreeable, compared with vision by refraction, which always shows them as if executed on *white paper*. A connoisseur may discover merit in a drawing on brown or violet-coloured paper, but the vulgar will hardly look at it; the prevailing tint disgusts them at once.

It is, however, a most fortunate circumstance, that this brownness in the light of reflecting instruments wholly disappears, or at least becomes insensible, when they are used with artificial light; in consequence, they are thus seen to the greatest advantage, and as we now have lamp-light brightened to perfect whiteness by oxygen gas, for microscopic purposes, and nearly equal to day-light for such objects as agree best with it, the reproach of a brown image will be in a manner done away with altogether from reflecting engiscopes.

* Whoever will be at the pains to look into the state of the figure of the metals of reflecting telescopes, and compare it with that of the elliptic metals of engiscopes, will find the latter (if they have been well executed) far more perfect than the former; for their figure being very nearly allied to that of a sphere, and moreover having a great depth of curvature, can always be kept from degenerating into that state of flatness at the edges which produces over-correction by giving the outside rays too long—a defect which seems almost inseparable from reflecting telescopes.

As Dialogue is that mode of writing in which a variety of contending opinions may be most naturally brought forward and answered, I have selected it as the best way of discussing the comparative merits of instruments: if the reader must know the names of the parties, I beg to inform him, they were Tobias Oldbuck, Esq. the naturalist, and Mr. William Putty, the optician. Lest I should be accused of putting nonsense into the former gentleman's mouth, I must state that he only expresses opinions current among the observers of this enlightened age, and which I have frequently encountered in society.

I must positively introduce my personages to the reader. Mr. O. is an old bachelor of about 60 (a descendant of the Oldbucks, of Monkbarns). He always wears a very natty wig, made by an eminent artist; his clothes are of the true scientific brown-study colour; he has not altered the cut of them, or the model of his hat, or any of his opinions on any subject, for the last ten years, and declares he never will, thinking it beneath his dignity either to learn or unlearn any thing at his time of life. Having described his costume—that outward and visible sign of a man's character, and which, indeed, conjointly with the periwig (which I have sufficiently described), constitute the man—I do not think it necessary to say any thing more about him, except that at one period of his life he was far gone, and most intently engaged in constructing achromatic object-glasses for microscopes, which, however, he abandoned as an impracticable bad job: when another person afterwards succeeded in producing them, Mr. O.'s pride was wounded in the tenderest place, for he considered himself a perfect giant in all sorts of microscopic science; in consequence, the sight of an engiscope ever after turned his stomach.

Mr. William Putty is an enthusiastic young optician, whose talents are of the first order; he has originated many capital improvements in microscopes, of which instruments he is very

fond; thinks we live in the golden age of these matters, and that we have left our ancestors far behind in all things pertaining to them. His character the reader will find is a complete contrast to that of Mr. Oldbuck.

Now it came to pass that one wet day Mr. O. was walking up and down in his study, occasionally surveying his wig in a mirror, and somewhat ruffled in his temper by the impertinence of the junior members of a learned body to which he belonged, who worried him, till (much against his will) he was forced to look into a very fine achromatic engiscope, which showed objects *too well* to please him. To vent his spleen he was indulging himself in the following soliloquy: "What occasion have I, or any man, for any other microscopes than single ones? vision by these is so perfect and satisfactory to me, that I want nothing better. *Was there ever any thing so ludicrously preposterous, as forming the image of an object, and viewing it by a species of microscope, called an eye-glass, instead of looking at the object itself with an eye-glass?* Are we not content with seeing nature itself? would any rational being rather behold a picture of a beautiful woman or landscape, than see the reality? What a monstrous perversion of all taste, to prefer art to nature! it seems to me little short of insanity itself. Away, then, with this nonsensical trumpery, and let me alone with my good, old-tried, staunch, simple microscopes."—Here Mr. Putty was introduced, who had brought home some trifling job; he met with rather a frosty reception, but instantly took up the word thus:

"But, my good sir, admitting the justness of your observations, these simple microscopes of yours are very imperfect things, generally equi-convex lenses of plate glass; by making them of other substances of higher refractive and lower dispersive power, they may be greatly improved."

"I shall not deny the truth of what you say, Mr. P., *theoretically speaking* at least, but I have looked through lenses made of diamond and other precious stones, but cannot satisfy

myself that I see any better with them than with those made of glass. Here, examine this opaque object with a single equi-convex lens of glass, having an angular aperture of 55°, set in a small silver cup; its sidereal focus is only one-thirtieth of an inch; or take this, it is one sixtieth of an inch, set in the same way, and has an aperture of one-sixtieth of an inch or 55° also? did you ever see any thing more distinct: the object is the scales of the diamond beetle, and would, from its brilliancy, be sure to show the aberration of the lens, if it had any, but you see the scales perfectly clear and distinct; will you pretend that such vision can be improved?"

"The vision is more clear and satisfactory than I could *à priori* have thought possible; but I do not see the lines on the scales well made out; on many of the scales, begging your pardon, I cannot see them at all."

"That is not the fault of the lens, but of the method of illumination, which is not of the kind required to bring out lines."

"But illumination has so wonderful a power in modifying the vision of many objects, especially those of the test kind, that it will sometimes make the better instrument appear the worse, and the worse the better; now, I could show you the said lines much better in an engiscope, because I can illuminate objects in such an instrument (especially opaque ones) any how I like; though I grant that I do not show you the lines themselves, but only a picture of them; so exact, however, that"—

"It will not impose upon me; I do not choose to trust to *pictures*, especially when I am exploring *unknown objects*; your engiscope (as you call it) may do vastly well to exhibit *known ones* to a parcel of women and children."

"Then you admit it to have the power of showing *known* objects; how and in what way can you ascertain that even your dear single magnifier can be trusted upon unknown objects, save by the experience you have had of their per-

formance upon those you are acquainted with? Your dogmatizing is an insult to reason and science, and unworthy of a reply."

"Well, I will admit (just to put you in humour again) that an engiscope may show such things as the lines in question rather better than my single lenses, but I should be glad to know if you can show me any *transparent object* better than they do, with any other sort of instrument; (now I have you on the hip.)"

"I perceive you are too much prejudiced against engiscopes, from *à priori* considerations to do them justice; they *ought to be* inferior to single magnifiers you think, and therefore you will have it they *must be so, and are;* but have you ever used compound magnifiers? they show you the real object as well as the single ones; and when scientifically made, are thought, by excellent judges, to perform much better, inasmuch as their aberration is far lower than that of equi-convex or even plano-convex lenses; in short, they would seem to afford us the *ne plus ultra* of perfect vision in contemplating minute objects under large angles."

"I have not used them much; they are things of great antiquity, and have been both in and out of fashion with naturalists many a good time and often, before now: when their power is high they are very inconvenient in the ordinary course of microscopic researches, from the closeness of them, when in focus, to the object; indeed, this circumstance precludes their use on opaque bodies altogether, and I candidly tell you, that when an instrument will not show opaque objects well, I am apt to reject its use altogether."

"In this you are very unjust. It is a law in optics and most other things, that when we gain an advantage one way, we must in general be content to lose it in another; it only remains for us to choose of what kind the advantage shall be; we must have one kind of instrument for one set of objects, and another for another, if we wish to avail ourselves to the

utmost of every good within our reach. To reply point-blanc to your former question, will you be content to admit the superiority of doublets and triplets, if I show you something with them in a decisive manner, which you will hardly be able to see at all with one single lens out of twenty, and then only in a most imperfect manner ?"

"I don't know: I am so confident of the excellence of my own lenses, that if you were to shew me any thing with another instrument, which I cannot see with them, I should be disposed to set it down *as an illusion of some sort or other*; and if you were to shew me any thing *in a different manner* from what they do, I should be very much inclined to think that they were in the right, notwithstanding."

"I thank you for your candour; this is precisely the way that every man *thinks* with respect to his favourite instrument, be it what it may, though he may not dare *to speak out* as you have done; it is 'poor human nature all over.' But, sir, this method of reasoning—I cannot see such a thing in my microscope, *ergo* it is an illusion; or, another man's microscope shews an object different from mine, *ergo* it shews it wrong, cannot be tolerated;—it may become a fine lady to talk in this manner, but in a pretender to science it is insufferable."

"Well, what is the wonder you are going to shew me? I suppose it will turn out to be the oblique lines on the brassica, you are always making such a fuss about,—an isolated instance, supposing the said lines actually to exist. I certainly have seen a few of the lines you allude to, with a doublet of about 1-20th of an inch focus; but, in general, doublets and triplets shew no more of them than single lenses do."

"I see plainly I shall have to fight the ground inch by inch with you; but I shall not despair of gaining the victory at last, 'if I have a fair field, and no favour;' at least in the opinion of impartial and unprejudiced bystanders, if any such there are. You say you have seen the lines in question, or

the *ghost of them* at least, with a doublet: now, have you seen as much with any of your adorable single magnifiers?"

"I have seen them occasionally, when they have been of very superior quality, and exquisitely set with a large aperture; but, I freely own, not with sufficient distinctness to convince me of their existence. The appearance somewhat resembles the tissue of a coarse piece of canvas, with the fibres running diagonally, when it is placed too far off from the eye to allow us to recognize the threads distinctly. The doublet makes this difference, that a thread here and there seems stronger and coarser than the rest, and therefore more distinct; but, as I have already observed, I am strongly disposed to think the whole an illusion, produced by oblique light."

"Have you ever seen the French brassica? The traces on it are still more difficult to exhibit, or fainter at least, than those on the English variety, particularly on that kind which is of the form of a heart, or like the head and tail of the other kind, abruptly joined together without the intervening portion; these may be said to make two other objects of the same kind. And now please to *prove* to me that all these are illusions: the *onus probandi rests with you,* and what arguments you are to use for that purpose I cannot imagine, unless they are *such as will equally serve to disprove the existence of any other delicate traces on tests in general:* beware of proving too much; many a logician has overreached himself in this way."

"I was trying against each other the other day three magnifiers, a triplet of 1-40th of an inch, a doublet of 1-70th of an inch, and a single lens of 1-60th; with none of these could I see the diagonal lines in question: all other lines and objects they shewed admirably well, and their performance seemed to me precisely alike, except, of course, as to power: all were made with the utmost care by a workman of the highest eminence, and were indisputably of the very first quality;

the apertures of all were fully 55°; the triplet I think more, 60° about. Now, sir, I candidly tell you, that I cannot believe that these three capital magnifiers would all agree in passing over unheeded the lines we are arguing about, if they really did exist, and allow a doublet, and a single lens of 1-20th inch focus, to have the merit of shewing them. It is this circumstance which staggers me—the conflicting testimony of various instruments and lenses; I am puzzled, as I should be were two highly respectable witnesses to aver they had seen such and such an event or thing, and two more, at least equally worthy of evidence, to assert that the actors in the affair were, to their knowledge, twenty miles distant from the place where it was said to have occurred at the time."

"You will frequently find a similar discrepancy in the performance of very excellent telescopes upon certain objects; the pole-star, for example. I have seen many excellent instruments of this class with large apertures, which shewed double stars, nebula, and clusters, in perfection—nevertheless, as blind as young puppies on this particular object—which a good achromatic of only two inches aperture will often shew; yet no astronomer has ever had the hardihood to deny the existence of the small star near *polaris,* or term it an allusion: a fine pickle, truly, would astronomy be in, if every observer had the privilege of denying the existence of every heavenly body he could not see in his favourite telescope!"

"Well, sir, suppose I concede to you this point in favour of compound magnifiers, what else have you to urge on their behalf?"

"I conceive it to be a just inference that they do actually exhibit all sorts of lined and ordinary objects better than single ones, though, from the coarseness of many of them, and the want of a requisite delicacy of apprehension in our eyes, we are not able duly to appreciate their performance on all occasions alike. It certainly happens to be the case, that the diagonal lines we are talking about are a sort of solitary in-

stance of the superior penetration of doublets; but if they had chanced to exist in the whole tribe of tests, then most certainly would the single lenses pass them over in all alike, and the doublets bring them out; at least, when of the requisite goodness. Let us suppose a telescope to be gifted with a sufficient power of penetrating into space to be able to shew the sixth and seventh satellites of Saturn, and that there happened to be no other bodies requiring an equal degree of illuminative power for their manifestation; then, perhaps, would the invidious assert that they were very probably some illusive appearance or another, as the telescope was not capable of shewing any other objects better than ordinary. I need not say how senseless, unscientific, and unphilosophical, such a conclusion would be; however, there is, as I think, another mode of demonstrating the superiority of compound magnifiers, which you will be satisfied with, sceptic as you are."

"Sir, I am all attention; what can this be?"

"Will you admit that the fact of our being able to discern some difficult test with a very low power is a proof of the goodness of the instrument we employ, and the lower the power the better the instrument?"

"It is certainly a very great convenience to be able to do so at any rate, and I should not hesitate to say myself, that an instrument which will shew me every thing I want to see, without forcing me to employ high powers, is, at least, a most useful and valuable implement for a naturalist, for a thousand obvious reasons, whether actually better or not than another which requires a higher charge of power for the same purpose."

"Well, then, here is a doublet made upon truly scientific principles, being the compound aplanatic lens of one kind of glass of Sir J. Herschel; its focus is one-sixth of an inch. Compound magnifiers, believe me, are at present far from that state of perfection to which they are capable of being brought, because the makers of them are generally pleased

to vie with each other in trying who can insult science the most grossly in the principles which they adopt, though I grant that they work excellently well, according to them. Now, with this magnifier I think you will find that you will see tests which cannot be discerned with any sort of single lens of the same focus and aperture, nor with this either, if you choose to reverse it, or turn either of the glasses the wrong way, so as to subvert the principle on which it is made."

"I like this sort of test a great deal better than the diagonal lines on the brassica; the name of Herschel carries with it weight and authority. I will verify the facts you state at my leisure; but I must give full loose to my scepticism in the meantime, and assert that I believe microscopes may be very good, and perfectly to be depended upon for making discoveries in all the ordinary branches of natural history and microscopic research, which will hardly shew any of these precious things you have set up as tests: a plague upon them! are we to be eternally bored to death with the dust of butterflies' wings and the scales of beetles? for my part I don't value them a rope's end?"

"Then you deserve to be made to appreciate the uses and properties of a rope's end at their full value; nevertheless, I will myself so far agree with you that I consider the whole family of lined tests as very exclusive sort of objects: it is very difficult to find others requiring the same penetrating and defining power; therefore the individual who first discovered and introduced them to the notice of the public, associated with them others, especially some difficult ones of the opaque class, which I hardly think any reasonable person can refuse to admit as proper tests for all microscopes, of what nature or kind soever may be the researches in which they are to be employed: such are the minutiæ of a fly's foot, the serratures on a human hair, the little pits on a mouse's hair, the tissue of the moss hypnum, and to these must certainly be added the eyes of several animalcules. If an instrument cannot

shew these, I suppose you would reject it as unworthy of confidence?"

"My dear sir, you now begin to talk like a rational being; I cordially agree with you: *all these things single lenses will shew in perfection.* Do you know I had such satisfaction the other day in shewing a young puppy the eyes of a wheel-animalcule with a single equi-convex lens: he thought, forsooth, to have come over me with his thingamy, his hang-his-cope, as I think he called it.

"You must not forget, that even the objects you admit as indispensable proofs or tests are not shewn, except by instruments likewise capable of shewing the *majority* of the lined ones, and that their goodness would be as well demonstrated by the lined objects as by a fly's foot, &c.; whatever shews the one will be sure to shew the other."

"Well, well, be it so; I am glad to find that we can go along with each other to a certain extent; and I hope you will appreciate my long experience and long habits of research, with regard to the minutiæ of natural history, as worth something, and that I have not adopted the opinion that single lenses are, upon the whole, *the most useful and effective working microscopes*, rashly. I shall always be ready to admit *theoretically* the superiority of compound magnifiers; but I believe it is only when they are of *a certain focus and aperture* that the eye really derives any advantage from the use of them."

"Have the goodness to explain yourself; I really do not comprehend your drift."

"Why, simply this: here are some equi-convex lenses, (very useful ones I find them), of $1\frac{1}{2}$ inch, 1 inch, and $\frac{3}{4}$ inch focus; I mean to say that I find no use in employing them with a larger aperture than that of my iris; and when thus reduced, I see no aberration about them; a little colour only is perceptible with an oblique illumination; they are, in short, as good as need be,—the finest doublet or triplet of the same

focus and aperture seems no better: if I even use an achromatic glass corrected by a concave lens, my vision does not seem to be improved, *because the aberration of the equi-convex lens was already quite insensible* to me: you see what a deplorable animal you have to deal with! You set before me a *salmis de becasses à la suprême,* and a bottle of *clos vougeot* to wash it down; and I think a beefsteak and a pot of stout as good or better food."

"There is some shew of reason in what you say, as we generally like any kind of food to which we have been habituated, however coarse it may be,—so do our eyes become coarse and indelicate in their perceptions, and satisfied with very ordinary glasses, from the effects of long habit; but of course, when we come to high powers, you will then admit the superiority of the compound glasses.

"Not at all: when we come to lenses of 1-30th, 1-40th, 1-60th of an inch, and upwards, it appears to me that their aberrations are so very trifling as to be insensible, even when only equi-convex. You saw how distinctly the 1-60th of an inch lens shewed the scales of the diamond beetle in the outset of our conference: I do not believe any practicable doublet would act any better; but it would, as you know, be impossible to get a doublet of this power *to shew an opaque object at all,* so the experiment could not be fairly tried. I have already told you the result of my trial of the doublet, triplet, and single lens, on the diagonal lines of the brassica; and to conclude, I verily believe that it signifies very little when we come to these high powers, whether they are obtained by single or compound glasses."

"Then do you actually mean to deny the superior efficacy of compound magnifiers altogether in all and every case: this is too bad!"

"Not exactly; that would drive you frantic altogether: I do think that there is a certain range of power, from about ¼ of an inch to about 1-20th, at which the eye is capable of

appreciating their superiority, and consequently of deriving advantage from it, (though it may not be much). When a lens, having a large angular aperture, is not of greater diameter than the pupil of the eye, so that all its marginal rays shall operate fully, it will, if free from aberration, make its goodness felt and recognized, provided, as I have already said, it does not run to an extreme in point of depth: now, in the aforesaid range of power, these conditions will occur; and it may perhaps be considered that the circumstance of the diagonal lines being best shewn by doublets of *about* 1-20*th of an inch focus,* and rarely by deeper ones, as well as the striking efficacy of the compound aplanatic of 1-6th of an inch focus, are a sort of confirmation of my hypothetical notions, on which, however, I shall not insist."

"Well, I am glad to be able to extort this unwilling confession from you, at last; I suppose you would consider single lenses, made from substances which naturally give as low an aberration as doublets and triplets, in the same predicament with them; and that you have no better opinion of diamond or sapphire lenses, or even of compound magnifiers made of them: indeed you said as much just now."

"How can I? I must of course be consistent in my principles; you will have a confounded hard task to prove their superiority in any other way than by reference to analysis, believe me."

"With such bigotted, obstinate, sceptics as yourself. But let us drop the subject of compound magnifiers: will you come and look at a beautiful aplanatic engiscope?"

"A what? stuff and porridge! prythee, leave off this ridiculous slang, and speak plain English."

"Well, then, a compound microscope,—but of wonderfully improved construction."

"I have no desire to see it: in the outset I told you my mind about these awkward unwieldy things; I can assure you

it has long been made up on the subject: and though I fully admit the magnitude of the improvements made of late on these instruments, and their superiority over the old ones, I consider them useless; except, perhaps, for the purpose of executing micrometrical measurements,—for which end I do not deny that they are somewhat more convenient than simple microscopes: however, we can measure the size of objects perfectly well without them."

"If you will not allow them any merit in an optical sense, you must admit that they are vastly more convenient than simple or compound magnifiers, for a variety of other purposes, as well as in executing micrometrical measurements, owing to the room they create between the object and the glass:—for dissecting; viewing bodies placed at the bottom of cavities; looking through the sides of a glass vessel containing polypi, chara, and aquatic insects; examining small parts of large bodies, not detached from their wholes, as opaque objects, and the like?"

"All these things can be done with single lenses also, *of the ordinary working powers:* I repeat, their assistance can be dispensed with."

"What say you to their large field of view? Is their achromatism also without merit?"

"I say that their field is no larger than that of a single lens, provided it is *so set that it can be brought very close to the eye;* for then, *by turning the eye about, an equal number of degrees of field can be examined:* the only difference seems to be, that in the compound microscope or engiscope, as you are pleased to miscall it, *the whole field* is taken in *at one swoop.*"

"That makes a vast difference, let me tell you: but will you not admit that the engiscopes fatigue the sight less than single magnifiers, when the power is high?"

"That is entirely an affair of habit; my eye is never

fatigued with the deepest single magnifiers: whatever instrument shews an object best will fatigue the sight least, be it what it may, as must be self-evident."

"I see you have rolled yourself up like a hedgehog, and present nothing to me but a ball of prickles, let me turn you over which way I like: however, if you are not afraid of meeting with an instrument you may chance to like better than your own, pray look at these scales of the podura in the engiscope."

"Afraid, indeed! a likely joke."—[*He looks.*]

"Can you say you have seen this object as well in your single, or I will say compound, magnifiers? say, on your honour!"

"I cannot say, upon my honour, that I have seen the lines so dark, and so decidedly made out; but the circumstance is easily accounted for by the *superior darkness* of the engiscope, which I need not say must be much greater than that of a single lens of the same power and angular aperture, having, of course, an opening equal in size to the visual pencil of the engiscope."

"Well, sir, that circumstance need not distress you; if making instruments darker will cause them to perform better, we can, God be praised, darken your single lenses for you to any required degree, with coloured glasses; but I will defy you to shew the object with them as you have seen it just now, do what you will with them; *not only are the lines shewn darker, and the spaces between them clearer, than with your lenses, but many which with single or compound magnifiers, of high powers, seem ragged and dotted, or rather an aggregation of dots, are shewn as veritable lines*; moreover, *you see the outline of the scale best at the same adjustment which serves also to bring out the lines**."

* My coadjutor, whose experience is very great, assures me, that this circumstance depends upon the state of correction in the objective as to sphericity,—the aberration of which must be overbalanced to exhibit the

"That is because the magnifiers shew them right, and the engiscope wrong; I do not believe that the lines on the scale are in the same plane with the margin of the scale, though they may be *nearly* so."

"Here is the old object, the diagonal lines on the brassica; look how strongly they are made out, and how *many more of them are visible than with the best doublets or triplets.* Can you doubt of them, really, now? Look, how beautifully, by a slight change of the light, all the cross stria come out."

"I told you before, engiscopes must not be trusted for exploring unknown objects, or making discoveries; the whole is an illusion."

"You say engiscopes cannot be trusted to make discoveries, *behold! they make them for you, and you will not believe in them.*

"I see your patience is nearly worn out, I will not plague you any more, except to view the diagonal lines on the brassica IN THE INSTRUMENT WHICH DISCOVERED THEM—THE REFLECTOR OF AMICI; they are shewn so decisively in this instrument, that *it would be as reasonable to doubt their existence as that of ruled lines in a copy-book:* doublets and *achromatics sometimes shew them, sometimes not,* but THE REFLECTORS NEVER CONCEAL THE TRUTH: moreover, *observe the perfectness of the longitudinal lines;* NO DOTS!"

"Pooh, pooh, man! of course the reflectors being still darker than the refracting engiscope, naturally shew these and all other objects darker; and this you call shewing them better."

Here Mr. Putty, who was one of those persons who can, on ordinary occasions, laugh in their sleeves without moving a muscle, and who had been long much tickled with Mr. Old-

grooves and contour together: again, a variation occurs according to the side of the scale which is viewed.

buck's humours, was fairly upset, and burst into a long scornful laugh; which Mr. Oldbuck, who mortally hated and dreaded any thing like ridicule, resented, as a gross piece of ill breeding, and an affront to his dignity; and so the conference terminated, both parties being unconvinced by each other's arguments, and remaining in their original opinions; Mr. Putty considering his engiscopes a signal instance of the glorious triumph which it is possible for art to achieve over nature, by the *destruction of aberration;* thus creating an instrument which, though it operates through the medium of an image, but of almost inconceivable perfection, is nevertheless capable of exhibiting all objects more perfectly than can be done by the best magnifiers; at least when the artist has been so fortunate as to produce a perfect system of object-glasses, with their aberrations exactly balanced, or a pair of metals exquisitely figured: Mr. Oldbuck, on the other hand, regarding them as a mere waste of labour, and prostitution of talent, quite unfit for philosophical purposes.—C. R. G.

POSTSCRIPT.

It only remains for me to say, as an epilogue to this little scene, that I have expressed my own sentiments in the character of Mr. Putty; and though I have formerly, in a paper in the Quarterly Journal of Science, given it as my opinion that it would be utterly inconsistent with the laws of nature and optics that engiscopes should ever equal the performance of magnifiers applied directly to the object, yet I am now convinced by facts, that those *now* made not only equal, but are capable, in a few rare instances, of surpassing them, especially if of the reflecting kind. The only instance I can point out in which an engiscope fails to do its duty, or what I

suppose to be such, is this:—we all know that a globule of quicksilver, like a convex mirror, forms a miniature image of every thing it is exposed to; a window for example: we know also, that we may, with a powerful engiscope, view, and magnify, and examine, this minute image, *provided the globule is not too small;* if it is, the engiscope makes a *blot* of light of it (like the spurious disc of fixed stars seen with a powerful telescope), instead of developing the features of which it is composed, for there can be no doubt that the most minute globule forms an image. A reflecting instrument, indeed, gives a smaller spurious disc than a refractor, and will also define the image of a smaller globule, but still, it fails at last. Now, whether magnifiers of high power would do the same thing or not, we have no very accurate means of knowing; for they approach so very near, when applied to objects, as totally to overshadow them, and thus preclude the formation of an image on the globule, except by means of a cup; and the illumination of the globule being accomplished in this way, of course we can expect to see nothing but the *image of the cup*, which may easily be mistaken, when on a very small scale, for a spurious disc. Now I have sometimes thought that this property of engiscopes causes them to give that appearance of dots or specks so visible in the tissue of the lines and markings on the grooved proof objects, especially the brassica, when viewed with aplanatic object-glasses *of great depth;* so that a small effort of the imagination would easily enable us to fancy that we actually saw the constituent particles or atoms of which the body was composed. This phenomenon may, with old specimens of scales, be, in some measure, owing to decomposition; at the same time reflectors cannot be said to shew it, but *there is no knowing what they might do if their objective part could be rendered of the same depth as that of the refracting instruments.* As to compensating for this deficiency, by *forcing* the power with eye-glasses of very short focus, it is a practice I have always reprobated, as it dilutes the image till, in my

opinion, there is very little reliance to be placed upon its demonstrations. The best doublets, triplets, and lenses of gem, seem to shew the dots and points much in the same way as the refracting engiscopes, but perhaps not so strongly marked. As for the reason why refracting instruments so rarely shew the oblique lines on the *Pieris Brassicæ,* and when they do, perform their task in so slovenly a manner, I must confess I am as much at a loss as why metals, having a large angle of aperture, should *so invariably* exhibit them; unless the reader is pleased to lay the circumstance to the account of the superior defining power of the reflecting instruments. Perhaps there may be some analogy between this object and the small star near Polaris, which is frequently shewn by small telescopes possessing great defining power, and passed over by others of large aperture, which shew all other telescopic objects perfectly, such as the minute stars composing clusters, and the like, which we should suppose *à priori* quite as difficult to bring out. This star seems also to melt away under the action of high powers, whereas there are others, to all appearance vastly like it, which cannot be seen till the field of view is rendered very dark, by a high power (*vide* Sir W. Herschel's Catalogue of Double Stars, in the Transactions.) I may observe, that I never saw these oblique lines with a power exceeding that of a 1-40th of an inch lens: all the *very deep* object-glasses and doublets I ever happened to use were totally blind with respect to this very remarkable object.

C. R. G.

CHAP. VI.

ON THE SPHERICAL AND CHROMATIC
ABERRATION, &c. OF EYE-PIECES.

It being still stoutly maintained that engiscopes and erecting eye-pieces, having foci in front of their anterior glasses, can be rendered achromatic by merely arranging their component lenses at particular intervals; and that "the intellectual and manual labour which has of late years been expended on the construction of achromatic object-glasses has been, in consequence, unprofitably directed*;" it is the province of the present work, and the bounden duty of its authors, to demonstrate the falsity of such doctrines, and to vindicate the truth of the

* *Vide* a Paper in the "Philosophical Magazine, and Annals of Philosophy," for August, 1831, No. 56, p. 112,—*On the Theories of Achromatization, by the Rev. H. Coddington,* in reply to a paper published by myself, "On the Chromatic and Spherical Aberration of Eye-pieces," in *Sir D. Brewster's Edinburgh Journal of Science*; in which, as it was in separate circulation at the time, Mr. C.'s answer certainly ought to have appeared, *unless it was intended to be read by itself, without reference to the paper it pretends to refute.* Mr. C. yields but one point, viz. the theory of the Gregorian telescope, constructed with mirrors of glass, which he admits to be somewhat imperfect. I think it will generally be found that if a man has an imperfection in his understanding, or method of analysis, which will cause him to be in error on one optical subject, it will operate on a vast number of others. The only favour I have to request of opticians is, that they will read the paper I have alluded to, or the present one, in conjunction with Mr. C.'s *candid and ingenuous* answer. In the former there are many typographical errors, which confuse my meaning in some places.

opposite principles, for the honour of the improvements lately introduced into use. If, indeed, the said dogmas and theories had been laid down by obscure individuals without influence, it would have been the wisest course to have allowed them to rest in peace and contempt; but, unfortunately, their authors are persons of the highest consideration and influence in the scientific world, by whom they are supported with all the parade of mathematical demonstration; and it may not without reason be expected that a large majority of that class of *savans*, who dare not, and perhaps cannot, think for themselves, will conceive it to be much more creditable to be in the wrong with men of such high eminence, than in the right with mere practical opticians. Yet it must be admitted that optics is both an experimental and demonstrative science, and it is well that it is so; and though experience ought certainly never to dictate to analysis, (which would be placing the cart before the horse, with a vengeance), yet, the testimony of the senses, and of those organs which are to use optical instruments, must not be wholly rejected. A telescope, and what is usually termed a compound microscope, or engiscope, pass into each other by insensible degrees, so that it is somewhat difficult to define the one from the other otherwise than by drawing a line of demarcation between them by reference to the length of the anterior and posterior focus of the object-glass: thus we may say that a telescope has its anterior conjugate focus, or the distance of the object from the object-glass, longer than the posterior, or that next the eye-piece. In an engiscope the case is reversed; perhaps, therefore, a definition of an engiscope, as distinct from a telescope, may be given thus:—it is a telescope made on a very small scale, having its object-glass, and the conjugate foci thereof, reversed. In support of the analogy between the two instruments, it seems proper here to remark, that an engiscope will act with a concave eye-glass just as a Galilean telescope, and that its focus can be adjusted by moving the eye-glass alone, instead of the whole body, as is usually practised.

The line of separation between them is where the two foci are equal: such being the case, we may make an object-glass of short focus, say four inches, gradually pass through all the gradations from a telescope to a compound microscope, without making the least change in the principle on which the image is formed. Now no optician has ever yet dreamed of making an achromatic telescope by arranging a system of glasses at particular intervals; though, if a compound achromatic microscope or engiscope can be so made, we ought surely to be able to construct a telescope, of some sort or other, on the same principle; the two instruments, as before stated, being so similar in their action of forming an image. It is a consideration also worthy of being attended to, that the first practical opticians in Europe have now all adopted the method of making achromatic engiscopes precisely on the principle of telescopes; that is, by *correcting the objective part by means of concaves of flint glass.* Such men as Fraunhofer, Utzneider, Amici, Selligue, Chevalier, Dollond, Tulley, would scarcely have all adopted so difficult a task as that of making these minute achromatic glasses, if it had been possible to obtain a perfect correction of chromatic and spherical aberration without them. They are all in the habit of making so-called achromatic erecting eye-pieces for spy-glasses, which are, in fact, nothing but compound microscopes; and it is hardly credible that they should not have perceived the application of them as such, if they were *bonâ fide* achromatic. But the fact is, these artists all know the fallacy of these things, and how, and under what circumstances, they are achromatic. I propose to shew that an engiscope cannot be made achromatic in any other manner than as a telescope is, and that the new achromatics are, consequently, not superfluous.

The angle of aperture of the erecting eye-pieces of spy-glasses is usually very small, not exceeding that of the object-glass they operate with, or about five or six degrees; the chromatic aberration, therefore, of what may be considered

their objective part, is nearly insensible to vulgar eyes, on account of this small aperture. For, *cæteris paribus*, the chromatic aberration of lenses is in the direct ratio of the square of their aperture, or the actual quantity of light they admit;—if, therefore, the size of the pencil is restricted to perhaps one tenth of an inch (the usual diameter of the stop between the first and second glasses of an eye-piece), it is wholly impossible that much colour can be generated. But if a lens of thirty inches focus has an aperture of five or six degrees, its diameter will be about two inches, and the quantity of colour generated by it eighty times stronger than in a lens of two inches focus with an equivalent opening. Moreover, it is well known that all working opticians are in the habit of over-correcting the colour in the object-glasses of those telescopes which are expressly made for viewing terrestrial objects. It is supposed by some, that the predominance of blue and purple rays, which is occasioned by this over-correction, tends to exhibit terrestrial objects better than they would be seen if the instruments were perfectly achromatic—an absurdity which I shall not take the trouble of refuting. *The real manner in which a beneficial operation is produced by this over-correction for colour, is by its effect on the eye-piece,* which it greatly ameliorates and improves, by neutralizing the red and orange light which would otherwise greatly preponderate in it, *so that the totality of the instrument may be considered sufficiently achromatic for practical purposes;* nevertheless, under certain circumstances, the uncorrected colour of the eye-piece renders itself very manifest—as, for example, when we view some dark object, such as the rigging of a vessel, or a weathercock against the light of a clear sky; for by placing the object at the edge of the field of view, while we look obliquely at it from the opposite side, so as to catch an eccentrical pencil, the uncorrected colour is instantly felt.

Now, as I am contending for the *principle* of achromatism, I shall proceed to shew that all erecting eye-pieces of the

ordinary construction, though they may, under certain circumstances, and in a practical point of view, pass for achromatic, *yet have, in good earnest, no achromaticity about them;* and of this I think any man may convince himself by the following experiment:—there is a small circular disc of brass, with a hole in it, placed between the two bottom glasses of all erecting eye-pieces, which, when the telescope is in action, serves only to exclude the false light which is reflected by the long tube: the diameter of the hole in it is usually about one-tenth of an inch, or just what will allow the pencil of light from the object-glass to clear it: the telescope will be just as achromatic without it as with it; when, however, the eye-piece is removed from the telescope, and tried by itself, as a compound microscope, the said diaphragm acts a very important part, and, in fact, reduces the angle of aperture of the eye-piece nearly to that of the object-glass of the telescope along with which it acted, being, as I said before, perhaps six degrees. Now it is no wonder that with so small an opening, though unassisted by the over-corrected object-glass, the eye-piece should still pass for achromatic with those who know not how to look into its defects,—just as we see Mulattoes and people of colour, who have not *much* black blood in their veins, pass for whites. Let, however, the said stop be knocked out, or, what will amount to the same thing, let it be opened out with a broach, until it will admit the whole of the pencil of a perfectly achromatic object-glass, *having a large angular aperture*—for example, one belonging to an opera-glass, or perspective, or or some of those dumpy achromatics which Ramsden was in the habit of making—this will probably cause an enlargement of the perforation of the said stop, from 1-10th to 3-4th of an inch, if the focus of the first glass is two inches. It may be known to have attained its proper size when the ratio between the diameter of the visual pencil and that of the object-glass truly represents the magnifying power of the telescope, or, when it is found by examining the pencil with a magnifier, that none

of the aperture of the object-glass is cut off by it. On trying any telescope thus mounted, it will soon be seen whether the eye-piece is achromatic or not: or the said eye-piece may be tried as a compound microscope, by itself; and I can only say, that a man who is not able to perceive colour in it must be either utterly blinded by preconceived opinions, or by a complete incapacity to perceive the faults of optical instruments*.

Nevertheless, *there is a construction for an erecting eye-piece which is* bonâ fide *achromatic to any angle of aperture,* as it appears to me, namely, a *simple reduplication of the Huyghenian eye-piece;* that is, using one to erect and form the secondary image, and another to view it, which will give a compensation to each part; but this construction is never employed, at least I never met with it, because, I presume, if we use a Huyghenian eye-piece to form a secondary image, the component lenses will be nearly of the worst figure, and in the worst position for giving distinctness†,—which is a quality to be preferred even to achromatism. I need not observe that such a construction could never be used by itself, as an engiscope, or compound microscope, because its focus being negative, or *between the glasses,* it can only be made to operate on an image already formed.

In the year 1815, being then a student in the University of Edinburgh, I began my career as a reformer of microscopes, from reading the article "Telescope," in the Encyclopædia Britannica, written by Professor Robinson, and chiefly from the consideration of a passage in it, which I shall here quote.

"We have examined trigonometrically the progress of a

* Vide Chap. XIX. p. 191, and particularly p. 200, of the "Microscopic Cabinet." Every thing I have there said concerning the art of looking into the defects of microscopes and engiscopes applies to erecting eye-pieces, *and also to telescopes, with very little modificaton.* He that hath eyes to see, let him see for himself, and be made a dupe no longer, either by fine-spun theories or great authorities.

† The ordinary construction rather resembles an Huyghenian eye-piece reversed, or inverted, which, of course, utterly subverts the achromatism.

red and a violet ray, through many eye-pieces of Dollond's and Ramsden's best telescopes, and we have found in all of them that the colours are united on, or very near, the field-glass, so that we presume that a theory somewhat analogous to our's has directed the ingenious inventors. We meet with many made by other artists, and even some of theirs, where a considerable degree of colour remains, sometimes in the natural order, and often in the contrary order: this must happen in the hands of mere imitators, ignorant of principle. We presume that we have now made this principle sufficiently plain. Fig. 20, No. 2, represents the eye-piece of a very fine spy-glass, by Mr. Ramsden; the focal length of its object-glass is $8\frac{1}{2}$ inches, with $1\frac{1}{10}$ of aperture, 2·05° of visible field, and 15·4 magnifying power; the distances and focal lengths are of their proper dimensions, but the apertures are a half larger, that the progress of a lateral pencil might be more distinctly drawn. The dimensions are as follows:—

Focal lengths, $Aa = 0·775$, $Bb = 1·025$, $Cc = 110$, $Dd = 0·79$.
Distances, $AB = 1·18$, $BC = 1·83$, $CD = 1·105$.

"*It is perfectly achromatic,* and the colours are united, not precisely at the lens ($C\ c$), but about 1-20th of an inch nearer the eye-glass.

"It is obvious that this combination of glasses may be used as a microscope, for if, instead of the image formed by the object-glass at F G, we substitute a small object illuminated from behind, as in compound microscopes, and if we draw the eye-piece a very small way from this object, the pencils of parallel rays emergent from the eye-glass D will become convergent to very distant points, and will there form an inverted and enlarged picture of the object, which may be viewed by a Huyghenian eye-piece, and we may thus get high magnifying powers without using very deep glasses. We tried the eye-piece of which we have given the dimensions in this way, and

found that it might be made to magnify 180 times with very great distinctness. When used as the magnifier of a solar microscope, it infinitely surpasses every thing we have ever seen. The picture formed by a solar microscope is generally so indistinct that it is fit only for amusing ladies; but with this magnifier it seemed perfectly sharp. We therefore recommend this to the artists, as a valuable article of their trade."

I caused that distinguished artist, Mr. Adie, of Edinburgh, to execute for me a microscope similar to that recommended by the Professor, on which no expense was spared;—it of course gave an erect image. I was not content with it, its construction being too complicated, and its length inconvenient; moreover, though its angle of aperture was no greater than that usually given to eye-pieces, its chromatic aberration forced itself occasionally on my unwilling conviction in a manner which I could not resist, in spite of my faith in analysis. I naturally, therefore, imputed this defect to Mr. Adie's imperfect execution, and set him to work afresh, to make another microscope, on the plan of an erecting eye-piece of the ordinary construction, gaining the different powers by the application of Huyghenian eye-pieces to the image formed by the two bottom glasses. I was very much pleased by the distinctness of this microscope, and so were all who examined it; still, however, it was not achromatic, so I set Mr. Adie down, at the time, for a bungler, who could not adjust the foci and intervals of the glasses in a proper manner, and determined to have the thing done effectually, if possible, by London artists, which resolution I executed afterwards. In the course of these experiments I found the utility of getting the power at the objective instead of the ocular end of the instrument, as a much sharper image was thereby obtained; I accordingly deepened what I shall call the object-glasses, as far as one-fourth of an inch focus, and obtained a very superior microscope, an account of which has already been laid before the public.

As to achromatism, however, I regret to state that the London workmen succeeded no better than Mr. Adie, though I thought a feeble compensation was produced sometimes when the curves of the two plano-convex lenses which composed the object-glass were turned towards each other in the manner they have been engraved. I moreover once thought that I had got a combination that was *achromatic upon opaque objects;* and being determined to leave nothing to be done by any man who should take up the subject after me, I resolved to apply to Mr. Tulley, of Islington, to have his opinion and advice on the subject. He soon convinced me of the impossibility of obtaining achromatism in any case where an image was to be formed from a real object otherwise than by the action of concaves of flint glass, and that my ignorance of the art of seeing the flaws and imperfections of optical instruments was the sole cause of my supposing I had ever obtained achromatism in any degree.

Now as my respect for truly exact science is not surpassed by that of any man, I must confess that all these circumstances created in my mind some doubts and misgivings as to the accuracy of Professor Robinson's statements and theories, not very much unlike what I have observed in farmers in the country, when unable to reconcile the actual state of the weather with the predictions of Moore's Almanack, in which their faith is altogether inflexible.

These theories of Professor Robinson seem to have been resuscitated by Professor Airy and Mr. Coddington. The work of the latter gentleman, "On the Refraction and Reflection of Light," contains the substance of Professor Airy's papers on these subjects; and whether it is considered as a work of originality, or as a compilation from the writings of our first opticians, it is admitted to be the best publication of the kind at present extant, whatever defects it may possess, and wants no feeble testimony of mine in its favour.

I presume, however, that the most staunch advocate for the

dignity of exact science, while he will insist on the vast superiority of its evidence over that afforded by the senses, will never contend that it is to run diametrically opposite to their testimony. I shall venture, though well aware of what I am doing, to impugn its infallibility, in the case of these theories of achromatism of Professor Robinson, Professor Airy, and Mr. Coddington, on the ground that *no artist is able to make an achromatic instrument according to them.* I shall oppose the said theories by what we call, in common language, *facts;* for I must state that when I view the subject theoretically I am utterly unable to detect the least flaw in them. It is not to be expected, indeed, that a poor sciolist like myself should be able to school men of such high mathematical acquirements as the aforesaid *savans;* the task must evidently be left to mathematicians whose calibre is still larger than theirs*. I have already partly expressed my own views concerning achromatism, and I shall endeavour now to expand them into the following propositions, which rest on the basis of the evidence of the eyes, or experience.

1. When achromatism is obtained by the adjustment of lenses to particular intervals, as in the case of the Huyghenian eye-piece, such achromatism is absolute and perfect, and not

* Analysis may, I conceive, be subject to the following defects :—

1st. It may be founded on correct principles, but false in its details.

2d. It may be founded on false principles, but correct according to them, and also in its details.

3d. These defects may be combined.

I should suppose the theories of achromatization I have impugned to be in the second predicament, and the false principle assumed, to be, that *the compensation for dispersion may take place any how, so that it is effected on the whole system;* and that the *double correction I insist upon is unnecessary;* and it must be confessed that, viewing the subject *à priori, purely in a theoretical manner*, nothing can be more consonant to right reason than *that one compensation should suffice, always supposing that it is possible to effect it on the whole, without giving a correction to the objective and ocular part separately*, which, however, does not happen to be the case.

like that effected by the combination of a concave lens of flint glass with a convex of plate or crown glass, which never effects a complete neutralization of the chromatic aberration, as is well known; therefore, if engiscopes and telescopes could be made by the adjustment of a system of lenses to particular intervals, their achromatism ought to be decidedly superior to that obtained by the action of concaves of flint glass, and equal to that of a reflecting instrument.

2. The only kind of achromatization produced by convex lenses, which is known in practice, is when two are adjusted to an interval equal to one half the sum of their focal distances, or thereabouts. These conditions are not rigorously necessary, as the lenses may be placed somewhat nearer than that. Moreover, the intervals seem to differ a little according as the eye-piece is adapted to an engiscope or to a telescope; at least if the power of the former is low, and the tube short.

3. Many modifications of this combination may be made,—as by doubling or tripling what are usually termed the eye and field glasses, so that the compensation for a double or triple eye-glass may be thrown upon a double or triple field-glass: also, there may or may not be an interval between the lenses composing the eye and field glasses: still, however, the mode of compensation is the same.

4. *In order to form a truly achromatic erecting eye-piece, or engiscope, there must be a compensation both in that part which erects and forms the image, and in that which views it; therefore no achromatic erecting eye-piece, or engiscope, can be made with so few as three lenses,* because either the objective or ocular part must inevitably be without compensation.

5. An erecting eye-piece, therefore, can only be made really achromatic, if we do not employ concaves of flint glass, by combining two Huyghenian eye-pieces, or some modification thereof, together, in such a way that one shall erect and form the image, while the other is made to view it. As to *the*

interval between them, or what may be termed the second and third glasses, if the eye-piece consists of four, it may be greatly varied—for example, from six to eighteen inches, and more—*without sensibly affecting the achromatism* ; the first and third intervals only requiring to be determined with precision.*

6. Such an eye-piece could only be used for viewing an image, and could never be employed as an engiscope, because it would have no external focus in front of the bottom glass; therefore, an achromatic engiscope can only have a double compensation in the same way as a telescope has it, of which latter instrument it is nearly a modification; and as it is exceedingly difficult to procure perfect flint glass lenses of large diameters for the object-glasses of telescopes, it is devoutly to be wished that, by the omnipotence of analysis, we may at length be enabled to construct them absolutely achromatic, of one kind of glass only, by adjusting a system of lenses to particular intervals; while with proper attention to the forms of the lenses, their spherical aberration *ought*, at least, to be reduced to insensible quantities, using only a small angle of aperture, though it could not, perhaps, be wholly removed.

Now, on comparing these propositions with those contained in Mr. Coddington's work, under the head of Achromatism, page 262 to 269, it will be seen how completely theory and practice contradict each other.

According to Mr. C.'s theories the following is a specimen

* Thus saith experience: behold what theory says,—supposing the first and third intervals, a and i, to be ascertained, and given to find the second, e, this will be represented *exactly, of course*, by the following singular expression (the four numbered fs being the foci of the four lenses in the eyepiece, namely, 3, 4, 4, 3, vide p. 266):—

$$e = \frac{\{2(a+1)-(f_1+f_4)\} f_2 f_3 - \{3ai+f_1 f_4-2(if_1+af_4)\} \{f_2+f_3\}}{3\{i(f_1+f_2)+a(f_3+f_4)\} - 4ai - 2(f_1+f_2)(f_3+f_4}$$

If $a = 4$ $i = 5$ then $e = \frac{72}{11} = 6.5454$.

of the dimensions of an achromatic erecting eye-piece, consisting of four glasses; *vide* pages 168 and 266.

	Inches.
Focal lengths	3 — 4 — 4 — 3.
Intervals	4 — 6 — 5·13.

when the axis of the incident pencil is parallel to that of the lenses: when it is inclined to them, the following variation in the intervals will occur, if I rightly understand Mr. C.:

4 — 6·558 — 5·43.

I suppose, with due submission to better men, an *achromatic* eye-piece *ought to be achromatic:* let any optician execute this; if it proves to be achromatic, I shall make the *amende honorable* to Messrs. C. & Co.

If the lenses in the aforesaid eye-piece have the best possible figures, as ascertained in p. 79, the spherical aberration will be reduced *so low as* 0.003; that of the single equivalent lens of the least aberration being 0·75. (*vide* 179.) I wish the makers of the achromatic object-glasses had in general the luck to reduce their aberration as low as this, with any large angle of aperture. I conceive that another false principle has been assumed by Messrs. C. and their colleagues, relative to the spherical aberration; viz. that, like the chromatic, it does not require a correction both in the ocular and objective part, but that the compensation for it can be effected *upon the whole any how.*

It will be a memorable instance of the fallability of analysis, even when conducted by minds of the very first order, if the said theories are found to be false and erroneous, as I am perfectly satisfied they are—"for by their fruits we may know them to be so." I have always found that good sound theories will produce instruments which satisfy the eye; and though it must be admitted that this organ is exceedingly coarse, and easily pleased in the generality of mankind, it is nevertheless, in many instances, capable of acquiring a refined and accurate taste in optical instruments, by a good education, just as it does in pictures and other works of art.

I once had the honour of looking through a telescope of the Gregorian form, but constructed with mirrors of glass, by the late Mr. Tulley, according to the theory of Professor Airy. Mr. T. had expended the whole of his skill upon the instrument, and had worked the said mirrors over and over again, a great number of times, till his patience was exhausted; yet the confusion in the vision produced was so great, that it was but just possible to recognize objects.

I think when such an artist as Mr. T. cannot bring a telescope something near to distinct vision, when working to the utmost of his ability by the theory laid down for him, it is not unjust to conclude that such a theory must be *rotten at the very core*. Can it be said that such sophistries are *useful* as serving to exercise the understanding? I should say that they can only serve to habituate it to fallacious hypotheses, unsound subtleties, and delusions of every description. We had better remain in the dark altogether, than be misled by such *ignes fatui*. If books cannot be written even on the exact sciences, without being full of errors, what is to become of those on other subjects—such as politics, medicine, religion, cosmography, &c. where men's passions are perpetually interfering to warp their judgments, and lead them astray from the truth? Such considerations certainly ought to teach the proudest philosopher a little true humility.

In the second volume of Mr. Hume's Essays, section 12, entitled "Of the Academical or Sceptical Philosophy," Part Second, there are some curious reasonings on the subject of mathematical demonstration, which the reader would do well to consult.

I may observe that Mr. Coddington has been at the pains of falsifying his own theories, practically at least, to the best of his abilities, by presenting to opticians a compound microscope, termed achromatic, which is constructed according to them. It is described in his treatise on the "Eye and Optical Instruments," pages 60 and 61, under the head of *Achromatic*

Object-Glass, and is represented in plate 13, figure 190. He has implicated articles 205 and 210 with the expressions in pages 261 and 263, in the Treatise on the "Refraction and Reflexion of Light," in the construction of this instrument; and if he had succeeded in making it achromatic, there would be good reason for asserting that it is unnecessary to correct the dispersion of its object-glass separately; since, if his theories were accurate, a much better and purer achromatism ought to be obtained by the simple adjustment of a system of lenses to proper intervals. I assert point blank that his instrument is as complete a failure as any thing of the sort I ever attempted myself. I have examined one of these instruments of the latest and most improved construction, (which, however, differed not materially from that described in the Treatise on Optical Instruments, except in having a double field-glass,) and can, I think, be positive that both *the chromatic and spherical aberration of the objective part was wholly untouched*, and that *the eye-piece, consisting of four glasses, was achromatic**. Nothing can surpass the beauty of the field of this microscope; but if I may be allowed the expression, not-

* I hope I shall be excused for quoting a part of a note to the first tract I wrote on the Amician reflecting engiscope; in which I have in a manner *described Mr. C.'s instrument beforehand*, as the said note was published in 1826, before his work and microscope were introduced to public notice:—

" I cannot here refrain from protesting against those preposterous accumulations of eye-glasses which we find in the best common compound microscopes (as they are called). It would appear that the worthy glaziers, who preside over the destinies of these unfortunate instruments, have not yet discovered the right end of a microscope from the wrong one; at least they have vented their rage for improvement entirely on the eye-piece; having first doubled the anterior eye-glass, then tripled it, and finally interposed a body-glass of long focus between the field-glass and object-glass (making the eye-piece to consist, in fact, of five lenses); they sit down contentded with their large flat field of view, and imagine they have arrived at the very extreme verge of perfection. The object-glass is allowed to remain a pitiful double convex lens, being, I suppose, either above or below their art."

withstanding its extent and flatness, nothing more can be made to grow in it than in that of any ordinary compound microscope having a well-figured object-glass of the same power and angular aperture, used with an Huyghenian eye-piece also of equal power with that applied to the instrument in question.

The dispersive and spherical error of small lenses is undoubtedly small, as I have frequently remarked, but it is not insensible, even with a very small aperture, to those who know how and where to look for it. Some persons see it at the first glance; others, only if it is pointed out to them; and some not at all, if it happens to contradict their hypothetical assumptions and preconceived opinions; for there is no blindness greater than that generated not in the organ of sight, but in the mind which receives its impressions. We are, indeed, so accustomed to tolerate aberration in microscopes, that it frequently is unable to stimulate our senses.

Now I shall not condescend to discuss the point whether it is right or not to correct the dispersion even of small lenses and object-glasses: but *how is it to be done by an achromatic eye-piece?* as in the case of Mr. C.'s microscope. If a man chooses to tell me that those little rainbows and fringes of colour which appear in objects viewed by chromatic instruments, are, in his opinion, highly ornamental, and not at all injurious to vision, I can only say I wish him a better taste.

If people like to eat dirt, they shall meet with no opposition from me: much good may it do them.

The only case, I think, in which colour can be said to be corrected by an eye-piece, is when an object-glass, over-corrected for colour, is made to act with a chromatic eye-piece, as I have, indeed, before stated: having once caused the object-glass of an engiscope to be over-corrected, because it was to act with an erecting eye-piece of the ordinary construction, the beneficial effect of this arrangement was very sensible, and it might either be said that the eye-piece corrected the object-glass, or the object-glass the eye-piece. I am of opinion that though it

would be highly advisable to get rid of the chromatic aberration of simple and compound magnifiers, it is not sufficient to produce any real detriment to vision, unless with exceedingly minute and delicate objects, beyond that of giving a *false colouring*, especially if *oblique light* is used. This, however, we soon learn to allow for; it is, moreover, considerably concealed by their spherical aberration.

As to the spherical aberration of object-glasses and metals, inasmuch as it is sensible to vision, I am persuaded, from reiterated experiments, that the power which an eye-piece possesses of modifying or altering it is exceedingly feeble, at all events. A case, however, in which I can be positive that it does actually correct it, is that of the Gregorian *telescope*, in which, if the primary metal is *very nearly* right in point of figure—for example, a little too much inclined to be spherical or parabolical—the error may be corrected by giving the secondary one an hyperbolical figure. Moreover, in the Cassagranian telescope, it is well known that the aberration of the two metals (supposing them to be both spherical) is equal to the difference between the aberration of the convex and the concave, which is a clear proof that an eye-piece may correct to a certain extent, *where a secondary image is formed*, (for I consider the small metals and eye-glasses of the Gregorian and Cassagranian telescopes in their combined action, as neither more nor less than eye-pieces*, which operate by forming a secondary image, like the erecting ones of common spy-glasses). I should, moreover, conceive that the same conditions would occur, if achromatic glasses of similar construction and effect, and, in equivalent states of correction, were substituted for the metals of the Gregorian and Cassagranian telescopes, and made to operate against each other on the same principle*. I have in vain endeavoured to find an in-

* An inverting eye-piece for either telescopes or engiscopes may be formed of a concave lens, in place of the two first glasses of an erecting

verting eye-piece *of the ordinary construction*, which would exert an influence over the state of spherical aberration of the object-glasses and metals of engiscopes, *when no secondary image was formed.* My way of judging was to form an artificial star by their unassisted operation as magnifiers in a solar opaque microscope, making the posterior conjugate focus to be of the same length as in an engiscope, that is, eight or nine inches; and having carefully examined the state of aberration in the picture, I then have attempted to modify it (when formed at the field-bar of an engiscope), by various eye-glasses, but so far as my eyes are capable of affording a criterion, I never succeeded in any degree: the image appeared as intractable as a picture formed by human hands, and remained inflexible both in its defects and excellencies, whatever they might be: the various eye-pieces I employed gave a better or worse field of view, were or were not achromatic, &c., as *regarded their own intrinsic operation:* for example, they might give the oblique pencil in a better or worse state; but if the said oblique pencil came in a confused or distorted state from the object-glass, I never could make them improve it. At the same time I think it proper to observe, that I never tried *thoroughly* the effect of positive over-corrected achromatic eye-pieces.

All these experiments, however, have convinced me that a compensation for spherical aberration cannot take place upon the totality of an erecting eye-piece or engiscope, unless both the objective and ocular part have a separate correction, for they cannot correct each other. I therefore believe that Messrs. C. and Co.'s nostrums for the cure of this evil are just as

one, combined with an Huyghenian eye-piece, which I consider an equivalent to the concave metal of a Cassagranian acting along with its proper eye-piece, and capable of exerting a similar action on the primary object, metal or glass; that is, of reducing its aberration in the ratio of the contrary aberration of the concave lens.

good as those for chromatic aberration.—Vide p. 168 and 179 of the *Treatise on the Refraction and Reflection of Light.*

I here give the construction of an erecting eye-piece or engiscope, which is both achromatic and aplanatic, to an aperture of about 27°, and having, moreover, a reasonable good correction of the oblique pencil.

Let there be two achromatic lenses of suitable focal length to give the required power, and let the anterior or first glass have its focus about half the length of the second: a stop may be placed between them in the solar focus of the first, to regulate its aperture, if necessary: to these let an Huyghenian eye-piece be applied at a convenient distance. It is not necessary that either of the lenses should be perfect in itself; they may be framed so as mutually to correct each other's aberrations, both spherical and chromatic. If they have their internal curves in contact, and are cemented together, there will be no sensible loss of light in this eye-piece beyond that in the ordinary ones; and in this case also the correction for the spherical aberration may take place in Mr. Lister's method, which will considerably facilitate their construction.

I have already stated that I consider the ordinary erecting eye-piece sufficiently perfect for practical purposes; but I think it would be a great improvement on spy-glasses if they could be shortened nearly one-half, so that they should be easily held and directed by the hand, when charged with a power of thirty or forty. I think an object-glass of two inches and a half, or three inches aperture, does as much upon terrestrial objects, at least *in the day-time,* as any other; the focal length of which is generally not less than thirty or thirty-six inches, which renders the glass too long to be easily used without a stand. If the focal length was reduced to fifteen inches, the angular aperture would thereby be doubled, and with it the defining power also (provided it could be perfectly executed). In this case the erecting eye-piece I have given would be indispen-

sable, for the colour of an ordinary one would become very sensible.

Trading opticians may not much relish my recommendations, but I say, and will maintain, that terrestrial telescopes will not have received their finishing touch, or have arrived at their *ne plus ultra* of perfection, until their secondary image is just as perfect as their first, and it can only be rendered so by being formed by regular achromatic glasses. Moreover, when we apply an erecting eye-piece to the object-glass of an engiscope, so as to obtain a low power, and for that end thrust it far into the body, so as to approach very near to the object-glass, (in which case what I shall call the posterior angle of aperture becomes considerable,) a truly achromatic construction is also highly requisite.

A positive inverting achromatic eye-piece for astronomical telescopes, or for engiscopes used with micrometers, may be made of two double achromatic glasses, having their convex lenses next the eye, with a certain interval between them, for the purpose of improving the oblique pencil. They may be either achromatic and aplanatic in themselves, or by mutual correction, and their foci may be varied at pleasure, provided that of the second or field-glass is not shorter than that of the first. I am sorry to say that I have not been able to procure any combination which gives so flat a field of view as I could wish, consistent with perfect distinctness. If it is thought worth while to obtain a large field at the expense of centrical perspicuity, we have only to reverse the position of the glasses, and that purpose will be accomplished.

It only remains for me to say somewhat about oblique pencils; they are very much mistaken who suppose that they have not received quite as much consideration as they deserve from those who have interested themselves of late in the improvement of the microscope. It is well known to every man practically acquainted with optics, and ought to be much better by those who know the science theoretically, that in all

constructions whatsoever there is *a perpetual system of gaining advantages in one direction, and losing them in another,* just as in mechanics,—what is gained in power is lost in time, &c. It is not permitted to man, assisted by the most powerful analysis, to combine together every advantage he may desire: he must content himself with what is attainable, according to the laws of the refraction and reflexion of light. I have ever found that all those constructions which give a very large angle of aperture, combined with great distinctness, invariably produce what is called a bad field of view; that is to say, the vision is only perfect in the centre. In refracting instruments a good deal may be done by combining several object-glasses together, more especially if they have intervals between them, (which, however, produce great inconvenience, by shortening the anterior conjugate focus, and thus precluding the use of high powers). As the action of metals is very simple in comparison to that of lenses, I shall give an illustration of the mischief occasioned by what is called improving the oblique pencil in the Amician reflecting microscope. It must be evident, that as the angular aperture is increased, the error of the oblique pencil must also be augmented, for it will come more and more oblique; now Mr. C. has actually recommended opticians to render the concave metals of the aforesaid instrument *spherical,* because in this case every pencil becomes equalized, and may be said to be equally bad or good, distinct or indistinct, throughout the whole field of view, though, so far as the objective part of the instrument is concerned, the whole instrument becomes utterly worthless, if this figure is adopted. They who work the metals of this instrument well know what infinite pains they have to get rid of this spherical figure, and to attain the true one*; and that when they have done so,

* I have known Mr. Cuthbert to have been *employed a whole week in getting rid of nothing but the spherical error* of one of his metals of 3-10ths of an inch focus and the same aperture, and not able to succeed at all in

the point is effected at the expense of a certain want of perspicuity about the edges of the field of view, which is altogether irremediable with low powers, which take in a large portion of the marginal part of the image.

If Gregorian and other telescopes, having a *large angular aperture,* are charged with a low power, the same defect is also very perceptible in them.

The Newtonian and Herschelian telescopes having very small angles of aperture, will admit of concave metals with spherical figures, because in this case the aberration occasioned by such a figure will be quite insensible. I do not, however, believe it possible to preserve a perfect spherical figure in metals having very small angles of aperture: for, in the process of polishing, it is sure to pass into the parabola at least, if it does not get beyond it, in spite of the utmost efforts of the workman. All that I ever examined are in the predicament of inclining to a hyperbolical figure, instead of a spherical one.

Of a piece with the performance of a spherical metal is that of a globular or bird's eye object-glass, which is considered to produce an excellent correction of the oblique pencils, because they come exactly like the centrical ones, which are utterly uncorrected, for the aberration of a sphere is to all outward demonstration much the same as that of an equi-convex lens, and requires as strong a concave to correct it.

When the omnipotence of analysis shall *point out some truly achromatic and aplanatic construction, which will give an oblique pencil as perfect as a centrical one,* then will the labours of mathematicians have assumed a proper direction. At present I am afraid they have been hallooing before they are out of the wood. I trust, however, that the time will

certain states of the weather, supposing always that a perfect figure was to be combined with a perfect polish.

come when the subject (which seems to me both useful and important) will be taken up in the right point of view, or it will be likely to remain a standing *opprobrium mathematicorum.*

It is quite plain that compound microscopes and erecting eye-pieces are only part and parcel of the subject of telescopes, and worthy of the same attention. Nothing which concerns the exact sciences can in my opinion be frivolous or unimportant: a mere subtlety or conundrum having the charm of exactitude about it, must always be respectable, although it may be of no apparent utility.

I shall leave it to others to judge how far the subject of microscopes is insignificant, or easily discussed; and I should recommend those who consider it theoretically, in future not to disdain to receive every assistance which experience and practical men can give them, before they embark in it "*out of sight,*" like Pantagruel and his companions in quest of the oracle of the bottle; and to remember the Laputan tailor, who being too great a mathematician to avail himself of any of the practical implements of mensuration belonging to his trade here in Europe, and working entirely by analysis, always sent home his customers' clothes damnably ill made at all points. It was in vain that he swore, down their throats, that their clothes *must* be well made, and were so, for he could not err in his calculations, &c.; he was only answered by derision, slaps on the chops, and kicks on the breach.

If we examine into the amount of the obligations opticians and optical instruments have derived from the science of mathematics, we shall find them fewer and less onerous than we might expect. Sir I. Newton certainly preconceived the possibility of correcting the chromatic aberration of lenses by the opposite refraction of a concave medium of greater density; but this discovery would have been of small use, if the spherical aberration could not have been corrected by the

same means: which was an idea which does not seem to have struck him, but was excogitated by a practical man, the elder Dollond, who seems to have made excellent telescopes long before any theory was in existence sufficiently correct for an optician to work by.

The late Charles Tulley, (certainly one of the first opticians of his day) assured me, that he never could find any theory, English or foreign, by which a *really good telescope* could be made*; all the calculations of curves he ever saw being more or less inexact, *and requiring after correction by trial, before an instrument made according to them could be perfected.* The best he ever met with are those of Sir J. Herschel, but these are faulty, and have too much aberration in the concaves, which he was obliged to reduce before he could make a perfect instrument by them. To Sir J. however, we are much indebted for some excellent aplanatic combinations for eye-pieces and magnifiers, which seem to leave nothing to be wished for or desired.

The Huyghenian eye-piece, a most valuable invention, was partly the result of experiments; Huyghens having purposed only to correct the spherical aberration of an eye-piece by his combination, which was afterwards found to be capable of correcting the chromatic also.

It cannot be denied, moreover, that we have been favoured with many excellent theorems and recipes for correcting the distortion produced by lenses, and obtaining what is called a good flat field of view: this is a subject on which the mathematicians have been more successful than any other. To them we likewise are indebted for the knowledge of the value of the aberrations of lenses of different figures, according to the

* The article Telescope, in Rees's Cyclopædia, was written by Dr. Pearson, but the *materiel* was furnished by C. Tulley. It shews how telescopes actually *are* made, and may be perfectly relied on, by the artist.

refractive and dispersive powers of the substances of which they are made, &c.

We have seen what theory has done for us in the case of erecting eye-pieces and engiscopes, &c. With respect to achromatic object-glasses for diverging rays, Euler has recommended us to reverse those of a triple object-glass made on a small scale—a wretched expedient, which will never make a good instrument. Probably in the course of about another century, long after the said object-glasses have been perfected by practical men, some pompous analyst will arise, who will buckle on some sort of *semi*-exact theory to them.

C. R. G.

CHAP. VII.

ILLUSTRATIONS OF THE ALTERATIONS

PRODUCED IN THE VISION OF CERTAIN MICROSCOPIC OBJECTS, BY USING INSTRUMENTS HAVING VARIOUS ANGLES OF APERTURE, BUT A *FIXED POWER*.

MR. J. MURRAY, of Albemarle-street, having, with the consent of Mr. Brande, allowed Mr. Pritchard the use of a plate formerly published in the 22d vol. of the Journal of the Royal Institution, with a paper of mine on Achromatic Objectives and Test Objects, I shall take advantage of the liberality and kindness of these gentlemen to present to the public a few illustrations of the said plate, as I have never written any thing on the subject of the present tract, except in the aforesaid paper. I must observe that when it was published, Achromatic objectives were quite in their infancy, the podura was unknown, and the diagonal lines on the brassica were undiscovered; nevertheless, with proper allowances on these points, the said plate will serve my purpose indifferently well.

As the subject is now pretty generally understood by the observers of the present day, I shall be brief in what I say, which must be understood as adapted to the calibre of the rising generation, and those readers who have not yet made microscopic science their study.

Fig. 1 is a very tolerable representation of an excellent and very beautiful test, a feather from the wing of Morpho Menelaüs, (being the first object in which I observed the very remarkable property of the lines as tests), as shewn by a triple object-glass of 2-10ths of an inch focus, and 1-10th of an inch of aperture, or $27\frac{1}{2}^{\circ}$. The cross striæ are not so numerous as they appear, when the object is illuminated expressly for the purpose of shewing them, when, indeed, it appears like a piece of brick-work ; but in this case the longitudinal lines are rendered much fainter; therefore a kind of medium illumination was employed.

The seven circular discs are supposed to pourtray a small portion of the said scale, seen with an object-glass of half an inch aperture, and 9-10ths* of an inch focus, used with a negative eye-piece of 1-4th of an inch, and having five different circlets or stops applied to it, so as to cause its aperture to vary from 1-10th of an inch (the usual aperture given to a lens of that focus in the old compound microscopes) up to half an inch, by a gradual increase of the size of the perforation of the stop.

Disc No. 1, Aperture 1-10th.—The scale appears quite dark all over; not a vestige of its lines is visible; even its blue colour is scarcely perceptible.

No. 2, Aperture 3-20th.—Very little improvement; the colour is lighter, the blueish tint more apparent; we may contrive, by looking with all our might and main, to fancy we see some indications of lines, or rather scratches.

No. 26, Fig. IV.—Aperture 1-5th of an inch, colour lighter and brighter; traces of irregular scratches are now clearly perceptible here and there: peradventure we shall see what we shall see, by and by, as the Mussulmans say.

No. 28, Aperture 3-10ths of an inch.—Land begins to be

* Fig. 13 represents the curves of this object-glass, but of twice their real radius, for the sake of greater accuracy.

seen from the mast head: a practised eye will now recognise the nascent lines, but they seem like an aggregation of dots, and are interrupted and broken: the spaces between them are still very dark.

No. 3, Aperture 4-10ths of an inch.—The lines are at length resolved, but not fairly; they are very faint, and seem ragged, as if still composed of dots and points, but more closely conglomerated than before: the spaces between them are still far too dark.

No. 4, Aperture 5-10ths, or without a stop.—The lines are as much resolved as they can be by an object-glass of so long a focus. They now appear in their true character, that is, pretty fairly drawn as if by a pencil of deep black lead on tolerably white paper, or, more correctly speaking, by a pen with some blue pigment on light violet-coloured paper; for their bluish tint is now abundantly manifest.

No. 5, Aperture naked as before, but the object turned one quarter round, in order to permit the illumination to operate on the cross striæ, which now become perceptible, though as a *minimum visible*, being by no means shewn so strong as in the plate: if the observer should not have seen them before with a deeper object-glass, he might be expected to consider their existence very dubious.

Such are the effects of various apertures on the object in question, the power remaining the same. For the information of such as are but young in these matters, it behoves me to remark that, *with so small an aperture as $27\frac{1}{2}°$, not one of the phenomena I have mentioned will be seen at all, unless the illumination is oblique.* Vide Figs. II. and III. shewing a plan and elevation of the relative situation of the object, and of the taper employed to shew it, when the illumination is conducted in a proper manner. If, however, the aperture is very large, and the object-glass deep, then the lines and cross striæ will be developed any how, or in spite of the most direct light which can be used, and this with a moderate power.

Figs. V. VI. VII. are examples of tests which are invisible with $27\frac{1}{2}^{\circ}$ of aperture, even when assisted with the most favourable light, and the greatest amplifying power: the regular microscopist will probably recognise in them the *pieris brassicæ,* two specimens of feathers from the clothes moth, and the scales of the diamond beetle (which are supposed to be here shewn as transparent objects): the minimum of angular aperture they require is about $36\frac{1}{2}^{\circ}$, consequently they can scarcely be shewn by any single object-glass.

Fig. V. is, of all other objects, that best adapted for a test, on account of its singular uniformity of structure. Mr. Pond, our late worthy astronomer royal, has noticed a remarkable feature in it, which is, that it is sure to be *invariably of the same length;* now I suppose if we were to collect all the leaves from any tree whatever, we should scarcely find two of them exactly of the same length, when subjected to strict micrometical measurement: and I think the same would hold good with respect to the scales of almost any other insect, and indeed to the other scales of the brassica also; I mean those not of the particular character here alluded to.

The effects of various apertures on the markings of this capital test are as follows*:—Up to $27\frac{1}{2}^{\circ}$, either in glass or metal, nothing can be observed about it *with certainty;* its surface appearing so nearly uniform, that no one who saw it for the first time, and did not know there actually were lines or markings upon it, would suspect their existence, whatever power may be employed. Between $27\frac{1}{2}^{\circ}$ and $36\frac{1}{2}^{\circ}$ faint glim-

* In this, as in all other cases, I always suppose the power used to be equivalent to the manifestation of the lines or markings, that is, inasmuch as a certain power is necessary to render the human eye capable of discerning them; but the object of this paper is to impress on the mind of the reader *the effect of aperture*, or, what is the same thing under another name, *penetrating power as distinct from magnifying power;* which latter is no doubt able to accomplish a great deal, but never can supply the place of a *large visual* pencil of light, which, as it is the ultimate effect of a large aperture, is another term nearly synonymous with it.

merings of marks of some kind begin to manifest themselves; with $36\frac{1}{2}°$ lines of a ragged, broken, uneven contour, are plainly seen, as well as cross striæ: if the objective is a *metal* of good figure, a *few* oblique lines will also be developed.

If the aperture is above $36\frac{1}{2}°$, and approaches to 55° *in glass*, (whether in achromatic engiscopes, compound magnifiers, or simple ones), the lines will be more strongly made out, but will appear to consist of an aggregation of points: the cross striæ will be shown closely packed together all over the scale, and occasionally a few oblique lines will be *faintly* exhibited: if the aperture is as much as 60° or 70°, and the object-glass or magnifier at the same time very deep, nothing but a tissue of dots and points will appear, occupying the site of the longitudinal lines.

The effect of $55\frac{1}{2}°$ of aperture in a well-figured *metal* of 3-10ths focus, is very different: the lines and cross striæ will not in this case be resolved into dots or points, but will appear in, what I suppose to be, their proper character; and the two sets of diagonal lines will be shewn with a force and effect which will leave no doubt of their existence in the mind of a candid observer; the various lines, the longitudinal, the cross striæ, and the two sets of diagonals, being all observable, *successively*, by a slight change of the illumination, though we can rarely see two of the systems well at the same instant.

Being aware that the invidious would be likely to assert that the scales and feathers of insects were objects *sui generis*, and that it was of little consequence whether microscopes and engiscopes, devoted to the examination of other objects, would shew them or not, I from the beginning associated others with them, which no naturalist can pretend to assert should not be properly exhibited by all instruments fit for philosophical investigation of the minutiæ of nature. Accordingly, fig. 9 is a bat's hair shewn as an *opaque* object; fig. 10 (*a*), a large mouse hair, shewn as an *opaque* object also; and fig. 12, a

fly's foot; (*b*) fig. 10 is a small mouse hair, seen as a transparent object; fig. 8, the fragment of a leaf of the species of the moss hypnum.

Now none of these can have their minutiæ properly shewn without an aperture of $27\frac{1}{2}°$ *perfectly free from aberration**; and indeed, if the aperture is much greater, it will be found vastly acceptable, by facilitating vision. The bat's hair sufficiently explains itself; the large mouse hair has pits in it, just like the interior of a tea-cup, and which ought to be made out as distinctly: the small mouse hair (which is shewn by transmitted light) has fine longitudinal lines connecting its joints, which are the most difficult parts to develop. The hypnum should have all its component lozenges distinctly made out: object-glasses will frequently shew the Meneläus, and other lined objects of a similar class, and yet not define these: reflectors are apt to boggle at them. I may observe that Mr. Pond has discovered, (by using object-glasses and lenses of *very large aperture* and high power), that what I have termed the lozenges of the hypnum are, in fact, hexagons, having two opposite sides longer than the rest.

The fly's foot has the following notabilia about it:—the lines on the hairs about the ancle at (*b b b b b*); the scales on the pastern (*c c*); the grooves on its claws (*a*); the white points (*d d*) on the soles of its feet, and the fine fringe (*e e*), which surrounds them.

As to the said drawing of the fly's foot, it is a wretched affair; because the said foot was fastened to a black cylinder with gum, and thereby sadly distorted, one of the claws being entirely sunk and invisible in the gum, yet it happens to shew all the minutiæ pretty well. Copper-plate engraving is not at all adapted to exhibit this object well; a wood-cut does much

* This is a condition which I always suppose associated with aperture; as without it the mere opening out of a glass to a large diameter does as much harm as good.

better: and in the succeeding volume (the first of the new Series of the Journal of the Royal Institution), the reader will see one which gives a better idea of it.*

Now, in order to illustrate my position about the value of aperture, in exhibiting so very ordinary an object—the foot of a common blue-bottle fly—I hope it will not give offence if I refer the reader to the celebrated Bauer's drawings of the same object, in the Transactions of the Royal Society for 1816, p. 146, belonging to a paper, entitled, "Some Account of the Feet of Animals whose progressive motion can be carried on in opposition to Gravity," by Sir E. Home; in which all the minutiæ I have detailed *are totally passed over*. In the wide world, where shall we find an artist who can delineate objects so beautifully and so faithfully as Bauer? What is the reason, then, that he has committed so many sins of omission in this particular instance? I answer, that the fault lay not with him, but with the instrument he used, which, though it might be one of the best which could be procured at the time he made the drawings in question (at which period achromatic objectives were unknown), wanted the penetrating power or aperture necessary to develop this object. Mr. B. drew exactly what he could see with certainty—nothing more or less, as was his bounden duty.

Why have I, in my drawings of the wheel animalcule, in the

* I have forgot which of the fly's feet I have drawn; they differ considerably from each other; but I think this was a hind foot. I have been told more than once that my drawing is unfaithful, because all the *minutiæ* I have represented *can never be seen at once*, as in the drawing. What could I do? This object requires a power of 1-30th inch for its development: as its surface is quite uneven, only a point can be in focus at once, or perfectly exhibited. Ought I to have made twenty drawings of it to shew it just as it appeared at every different adjustment of the focus of the instrument? The true way to draw it is surely to represent it just as it would have appeared had it been of the size of the drawing, and seen as ordinary objects are—a cat's paw, for example; *i. e.* without any instrument, or magnifying power at all.

"Cabinet," omitted to give the eyes, and a variety of other minutiæ since discovered in that animal? I answer, I had nothing but uncombined triple object-glasses to use, which, though they were fine things in their day, were utterly inferior in penetrating power to the triple systems of double achromatics now made. I drew just what I could see, nothing more or less.

To what are we to attribute the astounding discoveries of Professor Von Ehrenberg, in the organization of the Infusoria, in comparison with which all other microscopic revelations seem to shrink into insignificance, even those of Leeuwenhoek (supposing them to be correct)?

That creatures *generated without any primitive organic substance*, and so minute that we were formerly content to see little more than their outline, and many of which were supposed to be as simple in their structure as an hydatid, should be found to possess all the essential organs of the larger animals, and to be as perfect in their kind—to have the details of their whole anatomical structure laid open to us in so satisfactory a manner that we cannot entertain a doubt of their accuracy*—must be allowed to reflect eternal honour on the modern improvements on engiscopes; no less than on the skill, perseverance, and *profound* talent for microscopical and anatomical investigation, possessed by him who wielded their energies. Professor Von E. could not, I think (had he possessed no better tools to work with than the old microscopes), have succeeded in unravelling the construction of the Infusoria, however great the resources of his splendid genius may be: a good workman, it is said, never quarrels with his tools; but the subjects he had to work upon are totally invisible with in-

* *Vide* Organization, in der Richtung des Kleinsten Raumes. Dritter Beitrag. Von C. G. Ehrenberg: Berlin, 1834. Also, the Edinburgh New Philosophical Journal, for January 1836, p. 42.

struments which do not possess enormous *penetrating* power, combined with the requisite amplification; therefore, when we compare the illustrious Professor's drawings of the Infusoria with those of the same objects by Müller and the earlier observers, we are presented with a very fair illustration (making an allowance for the effects of colouring matter introduced in the systems of the animalcules) of the difference in vision produced *by large and small apertures;* for in the article of *magnifying power*, the old instruments were quite equal to those of the present day.

C. R. G.

CHAPTER VIII.

ON THE

CONSTRUCTION AND MANAGEMENT

OF

SOLAR AND OXY-HYDROGEN GAS MICROSCOPES, &c.*

The opinions respecting the apparent magnitude of bodies seen through optical instruments in general, are so conflicting, and often deviate so widely from the truth, that it is of great importance to be enabled to have recourse to any plan by which their admeasurements can be accurately determined. With the solar and gas microscopes, whose several properties I propose to consider, a method of doing this is readily supplied: for, by the contrivance of a screen, upon which the images or pictures of objects are formed, their superficial contents may be ascertained with the same precision as if they were the real objects themselves. In this respect, therefore, we have a remedy against those optical deceptions in the appearance of things, which frequently occasion no inconsiderable inconvenience to an observer. Nor is this facility of com-

* This Tract was originally intended to have preceded Chap. IV.; but it was found more convenient to place Dr. Goring's papers together, as his proofs had to be sent to North Devon for correction, and the engraver had not then completed the wood-cuts.

puting correctly how much an object is magnified the only advantage peculiar to them; for, with these and similar instruments, a number of persons can view a living object at the same instant of time, and remark upon its particular organization, functions, and habits, with great exactness, and satisfaction to themselves and to one another. The force of this observation will be sufficiently manifest, if we reflect that most diminutive living objects are constantly in motion, and that with the table miscroscope or engiscope, before a second observer can possibly note any peculiarity mentioned by the first, the creature will most probably have changed its position, and the part to which his attention was especially directed may be entirely concealed from his view. Persons of weak sight, who are unaccustomed to look through a table microscope, (for it does not occur to those who are well versed in these matters,) sometimes experience a little fatigue from the eye being intently fixed for any considerable time upon the same object, and subjected to the stimulating action of the intense light often thrown upon it for its illumination. The inconvenience arising from this does not apply to the solar and gas microscopes, the absence of which may therefore be enumerated very fairly among the advantages peculiar to them.

For the invention of the solar microscope we stand indebted to the good genius of Dr. Leiberkhun, who, about the year 1738, contrived an apparatus, by means of which a distinct resemblance of a magnified object, strongly illuminated by the condensed rays of the sun, (hence its denomination *solar microscope*,) was thrown upon a white screen, and rendered visible to any number of persons conveniently placed in a darkened room. To this gentleman's ingenuity we owe the valuable application, also, of the concave silver speculum, for concentrating the light upon opaque objects viewed through the table engiscope, as well as other improvements in that instrument. About the year 1774, Benjamin Martin published his description of the solar microscope, and its use in examining

opaque objects; subsequent to which, it underwent various skilful alterations in the hands of Messrs. Cuff and Adams, the latter of whom has given us a very minute account of the instrument, with drawings, in his quarto work on the Microscope, published in the year 1787,—omitting, however, it may be remarked, every particular respecting its optical construction. Since that time it has remained, until lately, quite stationary; and no practical work whatever has been written upon the subject.

In all the solar microscopes hitherto described, the optical part consists of a simple convex lens placed between the object (at a little more than its sidereal focal distance from it) and the screen upon which the image is designed to be thrown: hence it necessarily follows that they all have a considerable quantity of aberration, arising both from the figure of the lens, and the chromatic dispersion of the light. The former of these defects Dr. Robison in a great degree remedied, by substituting Ramsden's eye-piece in the place of the common lens; and Dr. Goring, by the application of achromatic lenses to the instrument, may be said to have effectually corrected them both*.

The oxy-hydrogen microscope, so attractingly exhibited in the present day, and unquestionably meriting all the encouragement that can possibly be bestowed upon it by the promoters of rational instruction, may be defined to be a mere modification of the solar, adapted to receive, and employ to the greatest advantage, the rays of an artificial light diverging from a central point, instead of the parallel rays from the sun. In the year 1824, Dr. Birkbeck delivered two lectures on optical instruments at the London Mechanics' Institution; in one of which he took occasion to delineate on a screen, by means of

* Mr. Benjamin Martin mentions in his works the adaptation of achromatic lenses to the solar microscope; but not being acquainted with the value of angular aperture, he only gave them the same as was usual with common lenses; hence they were laid aside as no better than the latter, and may justly be said to be re-invented.

a large magic lantern, representations of magnified objects intensely illuminated by the light emitted during the combustion of lime by hydrogen and oxygen gases*, and to indicate the practicability of applying successfully this method of illumination to the microscope. I would not omit, however, to mention, that, about the same time, Mr. Woodward instituted some experiments with the phantasmagoria, where the light was obtained in the same way†. In the interval between that and the present time, various amateurs and artists have studiously exercised their talents in perfecting the several parts of the instrument, which, like the solar, assumes its name from the source whence the light requisite to its action is derived.

In the present treatise I intend to lay before the reader a practical illustration of the construction of both the above-mentioned instruments, commencing with such parts of them as are common to the two, and then treating of those which are peculiar to each,—remarking also, as I proceed, on the various improvements they have recently undergone, and concluding with such instructions for the management of them as, I trust, will tend to remove those difficulties which have hitherto obstructed their being brought into more frequent use.

METHOD OF ASCERTAINING THE MAGNIFYING POWERS OF SOLAR AND GAS MICROSCOPES.

In all cases where the real dimensions of any object to be viewed with these instruments *is known*, the magnifying power may be readily computed, by simply measuring the length or breadth of the image or picture formed on the screen, and dividing them by the length or breadth of the object itself. Thus, for instance, suppose you had an object whose real length was the tenth of an inch, and whose image on the screen measured five feet in length, or sixty inches, the lineal magnifying power

* Mr. Cooper assisted Dr. Birkbeck in this experiment.

† Lieut. Drummond has ingeniously applied this light to Light-Houses and to Geodætical operations; *Phil. Trans.* for 1830, p. 383. See also the same work for 1826, p. 324.

of the instrument would be 60 multiplied by 10, or 600. But since the object has been magnified to the same extent in breadth as well as in length, the superficial magnifying power will be six hundred times six hundred, or 360,000; or, in other words, it would require 360,000 of the original objects to cover its magnified image. Some ingenious persons, whose design I suppose it is to astonish the world, carry their estimate to a much larger extent than this, and give to these instruments the marvellous power of exhibiting the solid as well as the superficial magnified representation of an object; but as it is clear that the superficies alone, without any portion of the thickness of the object, can be delineated on the screen, the superficial magnitude must suffice. The solid content is known (but cannot be seen) by multiplying the superficies by the diameter or lineal magnification. Another mode of determining the magnifying power is to measure the *distance* of the screen from the lens of the instrument, and divide that by the distance of the object from the lens. Thus—suppose the screen to be placed twelve feet distant from the lens, and the object one inch from it; divide twelve feet by one inch, and the quotient is 144, the lineal magnifying power of the instrument: consequently, the superficial magnifying power will be the square of 144, or 20,736. This result will not be accurately true, although sufficiently so for ordinary purposes: for in practice it is a point of difficulty to determine the *focal centre* of a lens from which the measurements ought to be taken, inasmuch as the thickness, form, and position (even of a single lens) must be considered, before the acting focal length can be strictly ascertained. In a combination of lenses, the matter of course becomes much more complex. I recommend, therefore, adopting the first method, and throwing the image of a micrometer upon the screen. In all cases where the magnifying power is not great, a disc with a circular aperture of known dimension, placed as an object, will readily determine its extent.

THE SCREEN.

The next thing in common, connected with the two instruments, is the Screen, upon which the image of the objects is displayed. In constructing this, every care should be taken to render its surface as smooth, white, and opaque, as it can be made; the chief consideration being, that it should reflect the greatest possible quantity of light, and absorb the least. The material usually selected for the purpose is a sheet of canvass properly stretched upon a frame, and painted with two or three coats of white paint; in doing which, some attention is required to smooth the surface between each layer with pumice-stone, or any other suitable substance, so that, when finished, it may be as plane and free from prominences or cavities as pains can form it. It is scarcely necessary to mention, that the purest white lead should be obtained, inasmuch as the brilliancy and perfectness of the picture will greatly depend upon the whiteness, and the sharpness of its outline upon the smoothness of the screen.

A screen of a superior kind may be produced by spreading a thin coat of plaster of Paris upon the flattened surface of a well-constructed wall. This, of course, will be a fixture; nor do I know that the last material can be used conveniently in any other way, unless on a small scale, when it may be attached to a moveable board or frame. The form of the screen will be regulated chiefly by the height and size of the room, and in some degree by the nature of the exhibition; but, in all cases where a circular one of sufficient dimensions can be contrived, it will succeed the best: it must be situated at right angles to the axis of the instrument. I may remark also, that, with the exception of the screen, the whole interior of the apartment should be made as black and sombre as possible, in order to produce a good effect.

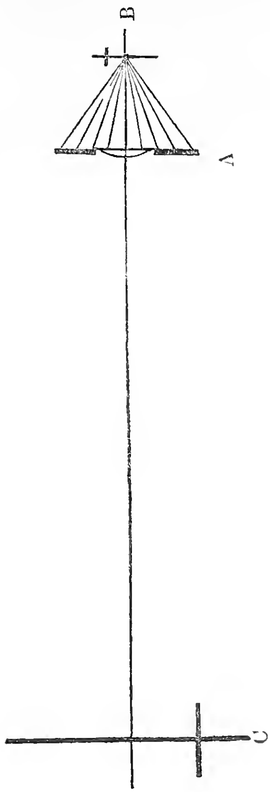
The position of the screen with regard to the instrument is of considerable importance; for if its centre is not placed opposite the axis of the instrument, and its surface in a plane every way at right angles to it, the picture will be a distorted representation of the object, its parts being magnified differently, according to their distance from the instrument.

CONSTRUCTION.

The optical construction of the solar and gas microscopes may be divided into two distinct parts: First, that which is necessary for magnifying the object, and depicting its image on the screen—which is, strictly speaking, the microscopic part; and, secondly, that by which the light is condensed upon the object—which may be termed the illuminating part. The microscopic part *may be* the same in both these instruments, and, by a suitable arrangement in the mounting, in the Table Engiscope also; but the illuminating part must of necessity be different. Pursuing the order, therefore, adopted at the commencement, I shall first describe that which is, or may be rendered, common to both—the microscopic part.

If we take a common convex lens, as shewn at A (Fig. 1), and place an object strongly illuminated at B, so that an image of it may be projected at C, that image of it will be an inverted magnified representation of the object. By a little consideration it will be evident, that all that portion of the light emanating from B, which conduces to form the picture at C, must pass through the aperture of the lens A,—the surplus rays, as indicated by the figure, being entirely obstructed and cut off. Now, in proportion as the picture C is enlarged, the available portion of the light will be spread over a larger surface, and consequently the picture will be more and more diluted. To remedy this defect, it would seem that you have only to extend the aperture of the lens by substituting one of

Fig. I.



greater diameter, which shall transmit an additional quantity of light; but, by doing this, the following evils will arise:—

I. The aberration occasioned by the spherical figure of the lens will be greatly increased, and the image will be less defined.

II. The dispersion arising from the unequal refrangibility of the light will produce a strong colouring throughout the image.

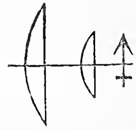
III. The aberration of the oblique pencils will cause indistinctness and colour around the edges of the field of view.

IV. The image being formed in a caustic, and not in a plane, it will not be distinct in all its parts on a flat screen, with the same adjustment of the instrument.

I shall now consider how these defects are to be obviated, taking them separately in the order I have noticed them.

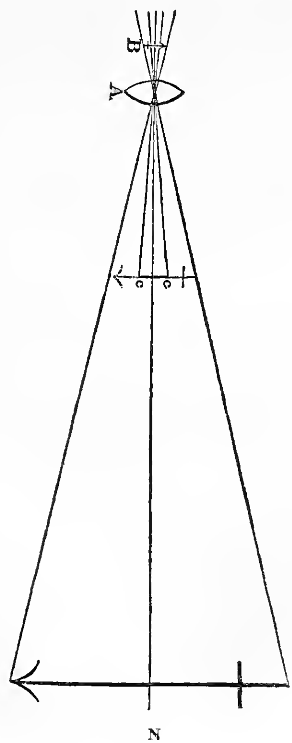
1. The first defect arising from the aberration occasioned by the form of the lens may be lessened by employing, in the place of a common convex lens, another of such a substance and form as shall cause the least aberration. To determine this, you must first ascertain the refractive power of the glass or gem of which the lens is to be made, and the distance at which the screen is to be placed from it; for it may be correct enough at one distance, but will not be equally so at another. It may be mentioned here, that, with ordinary glass, the form in most cases should be a plano-convex; the flat side being placed towards the object. But since the aperture in a single lens of the best figure cannot be greatly enlarged, it has been found expedient to have recourse to a combination of lenses. The most efficient combination I have met with for practical uses is a modification of Ramsden's eye-piece, before alluded to. When this is employed for high powers, it becomes of course the doublet of Dr. Wollaston, as described in the Microscopic Cabinet, p. 162. This combination, indeed, if properly executed, is the most efficacious that has hitherto been used for deep powers in the gas microscope. The form of the lenses and their arrangement is shewn at Fig. II. For further particulars respecting spherical aberration, see Microscopic Cabinet, p. 175, § 4, and p. 197.

Fig. 2.



II. The second defect, *chromatic dispersion*, arising from the unequal refrangibility of the light, may be remedied, as before mentioned, by substituting in place of a single lens an achromatic combination of lenses, which may be so formed as to obviate spherical aberration also. In the solar microscope, this combination has been used with considerable advantage; and there can be little doubt, that, for all scientific purposes where the utmost definition and correctness are required, it is by far the most perfect construction of any that has been hitherto discovered. It might probably be inferred from what has been said, that an achromatic object-glass completely rectified for a table engiscope would of necessity be adapted

FIG. III.



for the solar; and so it would, as far as the two instruments correspond: but since the *angle of the field of view* in the former is generally much less than that in the latter, an achromatic object-glass suitable to the one *may be* wholly unfit for the other, and thus be found quite defective. For instance, let A (Fig. III.) be the object-glass, B the object, and *c c* the diameter of the *field-bar* of a table engiscope: now it is evident, that so much only of the object can be seen in the engiscope as occupies the space *c c:* but the illuminated disc, or field of view, on the screen of a solar microscope, should subtend a larger angle than that subtended by *c c*, viz. that under G G: all the marginal rays, therefore, beyond *c c* may pass uncorrected, and consequently may produce a distorted, coloured, and undefined picture.

It may be remarked here, that the field-bar of a table engiscope generally subtends an angle of from five to ten degrees, and seldom or ever exceeds fifteen; whilst the solar and gas microscopes should admit of an angle of nearly thirty degrees; indeed, I have seen some which subtended 45°. As, therefore, the area of the field of view in both instruments varies as the square of their diameters, in the most favourable case the latter will be four times the extent of the former.

The construction of achromatic object-glasses having been amply treated of in our other works, it would be improper to repeat it here: there are, however, a few observations connected with them that suggest themselves, which, if completely carried into effect, would probably render the solar microscope the most valuable instrument which the naturalist can possess, enabling him to obtain larger angles of aperture, and greater space between the object and magnifiers,—the first giving increased means of penetrating into the structure of bodies, and the latter affording practical facilities in the admission of objects, the want of which renders the best reflecting microscopes useless for the examination of a numerous class of objects.—First, then, the posterior focal distance of the object-glass in

a solar microscope being longer than in an engiscope, enables us with it to obtain a larger angular aperture without any augmentation of its real aperture, while it is now well ascertained that, in proportion as we reduce the length of the body, (that is, shorten the posterior focus of the object-glass or distance A *c*, Fig. III.) we must reduce its aperture to obtain all the necessary corrections. Thus, for example, suppose we have an inch-triple achromatic object-glass, and employ it with a body ten inches long, we may obtain an angle of aperture of 18°; but if we shorten down the body to five inches, then, to obtain the requisite corrections, it will be necessary to reduce its aperture to about 14°. Hence, in solar microscopes, where we have the posterior focus elongated twenty or thirty times, it is probable that a much larger angle of aperture might be obtained; and thus, with an object-glass of no shorter focal length than one quarter of an inch, we might probably obtain an aperture sufficient to penetrate into the structure of every object we are now acquainted with.

I should not omit to notice, that when the bodies with deep object-glasses, say one-tenth of an inch focus, are reduced one-half, their angular aperture remains nearly the same; and the reason is obvious. In the case of the inch object-glass we reduce the proportion between its anterior and posterior foci as low as one to five; but, with the same reduction of body and the one-tenth object-glass, the proportion remains as one to fifty.

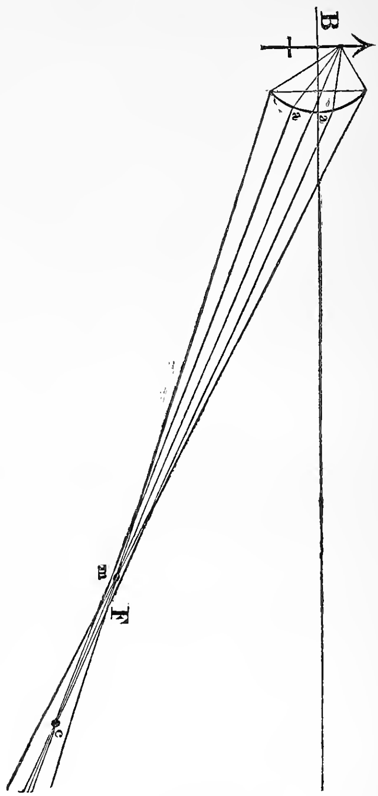
I may remark, as a caution to those who fit up solar microscopes with achromatics, that the lenses must not be cemented, as they may in use be soon spoiled by the heat of the sun.

The practical rules for determining how far any combination of lenses is free from chromatic dispersion, are amply detailed in the Microscopic Cabinet, p. 200: see also Test Objects, chap 16.

III. The third defect, the aberration of the oblique pencils of rays, will be better explained by referring to Fig. IV., where B represents the object: from any point B' not in the

axis of the lens, let a pencil of rays be incident upon the lens, and refracted to form an image at that point at F. From the

FIG. IV.

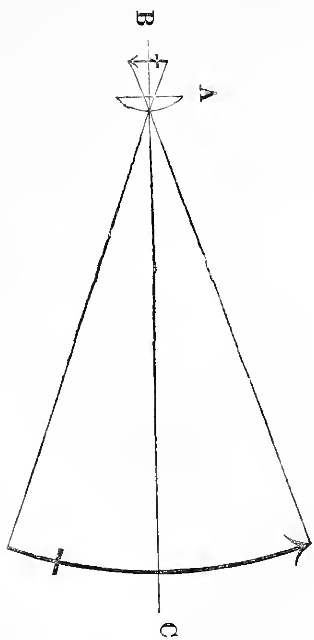


spherical figure of the lens, the extreme or marginal rays of the pencil will undergo greater refraction than those represented by *a a*, nearly coinciding with the axis of the pencil, and will meet at *m*, the focus of marginal rays, whilst those near the axis of the pencil will proceed on to *c*, the focus of central rays; consequently, an indistinct circular representation of the point B will be found between *b* and *m*, the longi-

tudinal aberration of the oblique pencil. A similar effect will take place in all the other pencils passing through the lens from every point of the object B.

This aberration of the oblique pencils may be corrected by a proper form and combination in the achromatic object-glass; for although it is a manifest and visible error, it would not be advisable, in practice, to construct a form exclusively to remedy it, unless, indeed, when very low powers only are to be employed; in which case it can in a great degree be done by a right adjustment as to distance of the lenses shewn at Fig. II., and giving their surfaces the necessary curvature, so that the defect will be imperceptible.

Fig. V.

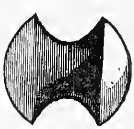


IV. The last defect I have to notice, will also be better understood by a direct reference to Fig. V., where A is the lens,

B the object, and C its image. As the several portions of the object B are at unequal distances from the centre of the lens A, the image C, instead of being formed on a plain surface, will assume a curve, as represented at C. To remedy this, it is only necessary that the screen should be constructed of a corresponding curvature; but, in practice on a large scale, this will be extremely difficult: moreover, with every change of magnifying power, or variation of distance between the lens and the screen, a new curve for the latter would be required. By adopting the converse method, however, and mounting the object between two surfaces of the proper curvature, such as watch-glasses, an image will be seen equally distinct throughout the entire field: thin sections of vegetables, specimens of gauze, lace, and other flexible substances, are viewed extremely well when mounted in this way, especially when the angle of the field of view exceeds 30 degrees; although it is not advisable to employ a larger angle if it can be avoided.

Mr. Coddington, who appears to have been the first person to investigate this error in microscopes, has succeeded to a great extent in correcting it, by substituting spheres of glass in place of other lenses. This contrivance is shewn at Fig. VI., where the aperture of the sphere is defined by a groove cut about its equatorial parts.

Fig. VI.



"The only point of consequence is," says Mr. Coddington, "that the rays which pass through this magnifier should traverse both the refracting surfaces without any obliquity, by which means the whole field of view is equally distinct." The two refracting surfaces here alluded to are, of course, portions

of the same sphere, and, if continued, would meet. I have made this remark simply because, in all the Coddington lenses that I have examined, there is a great fault in the making of them: few, if any, do form perfect spheres, if thus continued. Mr. Coddington has recommended me to make these spheres of rock crystal;* and Sir D. Brewster considers that they would be quite perfect, if composed of garnet, and used in homogeneous light.

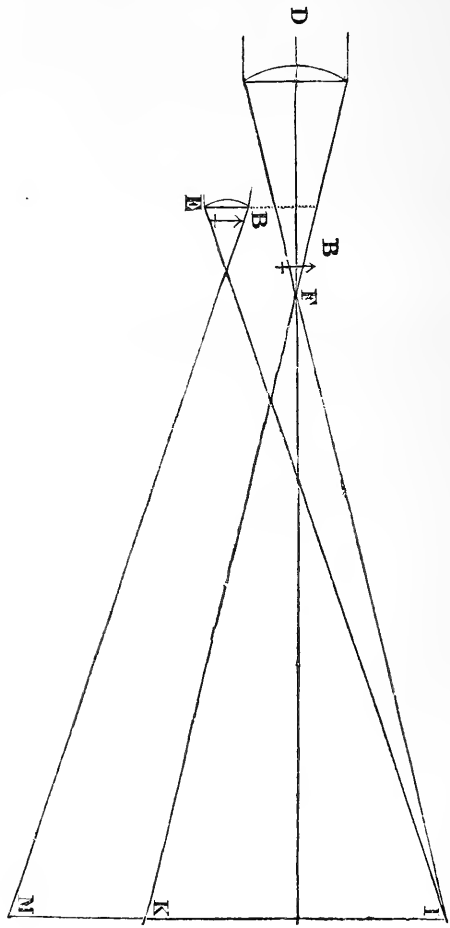
FOCAL LENGTH OF MAGNIFIERS USED IN SOLAR AND GAS MICROSCOPES.

The range of magnifiers suitable for either of these instruments depends upon the dimensions and arrangement of their illuminating apparatus. In the larger ones, which are by far the most instructive and amusing, and best adapted for public exhibitions, a great extent of surface can be intensely illuminated, and therefore very feeble magnifiers can be employed; the lowest having a sidereal focal length of about three inches, and thence proceeding upwards to a quarter of an inch. If they are much shorter than a quarter of an inch, unless the field of view be small, and the instrument very accurately constructed in every part, the image on the screen will be little more than a gigantic coloured shadow of the object. Indeed I may safely assert, with respect to the gas microscope at least, that, with its most extravagant magnifying powers, none of the minutiæ of an object have been displayed which could not be seen through a simple microscope with a single lens or doublet of a quarter of an inch sidereal focus. With the solar, a magnifier as high as the sixteenth of an inch may be advantageously employed, although half that power will be

* I find, with this medium, that a slight obliquity produces double refraction.

found amply sufficient for most scientific purposes. I am aware that, in Germany, the polygastric sacs, or stomachs, in the smallest genus of animalcules, the Monads, are said to have been rendered distinctly visible with the solar microscope; to effect which, a power of the sixteenth of an inch, if not a deeper one, would certainly be required. The most splendid

Fig. VII.



solar that has ever been produced in this country had a set of achromatic lenses, whose foci ranged from an inch and a half to two-tenths of an inch; but, in some that I have made with achromatics of two inches focus, even their superiority over common lenses was decidedly manifest; and, as the powers become deeper, the advantages to be derived from the achromatic construction increase in a high ratio.

ILLUMINATION FOR SOLAR MICROSCOPES.

Transparent Objects.

Fig. VII. will illustrate the construction of the illuminating apparatus of a solar microscope. D is the large convex lens for condensing the parallel rays of the sun; F the sidereal focus of the lens D. The condensed rays of light, after crossing at the point F, will diverge towards the screen I K M, and may be supposed to occupy the space I K. Now, if the instrument be so constructed as to require the object to be placed at the point B, it is evident that the central portion of the object through which the condensed rays must pass, will be powerfully illuminated. But if the microscopic part of the instrument, viz. the magnifier, will take in a larger portion of the object than is thus illuminated by the lens D, it is evident that we shall not obtain so extensive a field of view as the microscopic part of the instrument will admit of. To supply this deficiency, an additional lens E, as shown in the drawing beneath, may be introduced at the dotted line, the effect of which will be to make the rays converge to a point much nearer to the lens D than is its sidereal focus F, and consequently to increase the angle of divergence I F K,—thereby occasioning the rays to illuminate an enlarged space, I M on the screen, by which means the field of view is greatly extended. If the object B be now placed close to the *field lens* E, every portion of it will be illuminated. As, however, different sized objects require differ-

ent magnifying powers to display them properly, it is necessary, in like manner, that the field lenses be suitable to the powers employed.*

Since it is necessary that the sun's rays should pass *directly* through the lens, in order to form a proper disc upon the screen, it will appear evident, either that the axis of the condenser D must be directed towards the sun, or that a plane mirror be so placed behind D as to reflect those rays along its axis. The latter method is usually adopted, as being by far more convenient and simpler than to be continually changing the position of the instrument and of the screen. It is important that the mirror be made as perfect as possible, lest a considerable portion of the light be absorbed, or otherwise injured. For this purpose we generally employ a silvered looking-glass, (a speculum of sufficient size being too costly,) which should be of *thin* Dutch plate-glass, as free from colour as it can be procured : if it be not thin, the images of the sun reflected from each of its surfaces will be so far separated as to be visible on the screen, projecting a double image of the object, the one overlapping the other.

The intensity of the light condensed upon the object by the lens D, Fig. VII., (if there were no light lost in reflection from the mirror, or from the surfaces of the condenser, and none absorbed in passing through it,) will be in the proportion of the squares of their respective diameters. Thus, if the diameter of the condenser were six times that of the object, the latter would be illuminated by a light 36 times as intense as that direct from the sun. If it were wished therefore, to magnify, the same number of times, two objects of unequal size, which should be equally illuminated, it is clear you would not require so large a condenser for the smaller object as for the other :

* In all solar microscopes, the construction requires the illuminating rays from the object to be converging; but it is probable, if they were diverging, that a superior definition would be obtained, as is found to be the case with delicate objects under an engiscope.

hence, for a solar intended to exhibit large objects, where a considerable surface of condensed light is absolutely necessary, or where very high magnifying powers are to be used, which greatly extend the disc over which the light is to be spread, a condenser of comparatively large diameter will be required.

The diameters of condensers for solar microscopes vary from an inch and a half to about six or seven inches,—those of four or five inches being the most convenient and generally useful. If they are much smaller than that, they will not sufficiently illuminate large objects, and are consequently suited only for a limited class of them; and when they exceed seven or eight inches, the heat becomes so intense, that it will scorch and burn up the objects placed in or near the focus, and even fuse the magnifiers themselves.

Having determined on the diameter of your condenser, the next point to be considered is its focal length, which should be such that the prismatic dispersion may interfere as little as possible. If the focal length be too short, the image will be coloured, notwithstanding you have an achromatic object-glass; and if it be too long, it will occasion great strain upon the instrument. Those I have found to answer the best have been in about the proportion of four or five times the diameter. The foci and diameters of the field lenses (see E, Fig. VII.) must be decided upon by trial, after the magnifiers or object-glasses have been selected.*

Under any circumstances it will be evident, that whenever a single condensing lens is used, some portion of the light will of necessity be dispersed; but if there were substituted in its stead a portion of a paraboloid reflector, as proposed by the Rev. Mr. Packman, this defect would be entirely obviated, and you would therewith collect an intense spot of pure white light.

* See p. 87.

Fig. VIII.

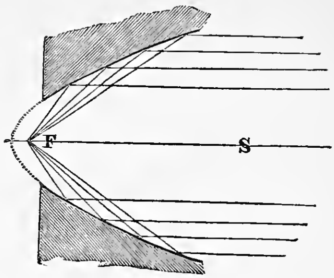


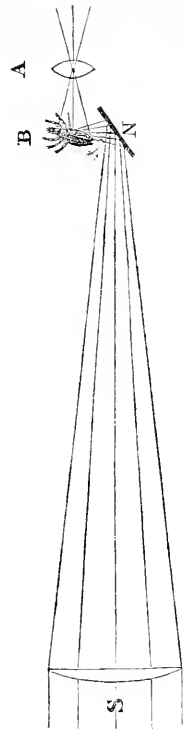
Fig. VIII. represents a section of such a reflector, with its apex cut off; F is its focus for parallel rays, within which the object is to be placed. By a principle of the parabola, all the rays of the sun impinging upon its surface will be reflected towards F, without aberration or dispersion; and thus the object intercepting them will be intensely illuminated without any coloured fringes.

Opaque Objects.

The usual method of constructing a microscope for displaying this boundless class of objects, in all their varieties and beauties, augmented by the reflection of the solar light condensed upon them, is shewn at Fig. IX., where S represents the condenser, B the object, N a small reflector, and A the magnifier. Since, in this case, the light is to be reflected from the object, and not transmitted through it, a plane reflector is placed at N, in order that the condensed rays falling upon it may be thrown upon the object, and thence proceed, as in the case of transparent objects, to depict its image on the screen. The reflector so used is generally a piece of looking-glass, acted upon by an adjusting screw from behind, so as to vary its inclina-

tion, and suit the different objects to be viewed; but here a small speculum would be an improvement worth the additional cost.*

Fig. IX.

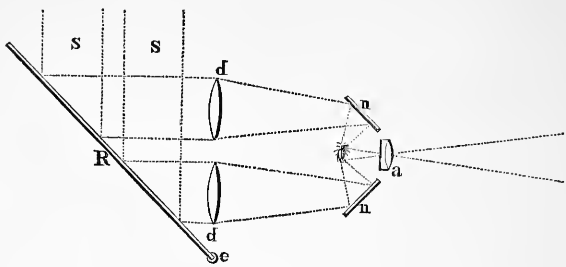


Another method of illuminating opaque objects is by means of four smaller condensers arranged in a circle, from which the condensed light, ere it arrive at their focal points, is received upon four small reflectors so situated as to throw the whole of the light upon the object. This plan will be readily understood by a reference to Fig. X., where *d d* represent two of the four

* See Fig. III. p. 85.

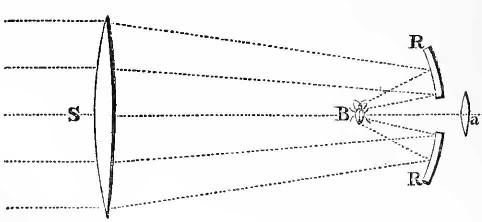
condensers, *n n* their corresponding mirrors, and A the position of the magnifier. An instrument thus constructed has been made in America, and found to answer very well.

Fig. X.



The following plan, contrived by myself, has many advantages. It consists of one condenser (the same as is used for transparent objects) and a silvered concave spherical reflector, or cup, with an aperture through its centre to admit of the condensed light proceeding to the magnifier. This arrangement is given at Fig. XI., where S is the condenser, B the object, R the concave reflector, by means of which the rays, partly condensed by passing through the lens S, are collected and thrown upon B, and thence proceed through the aperture to the magnifier or object-glass *a*.

Fig. XI.



By observing the preceding construction, it will be evident, that if the concave reflector R were of equal diameter with the

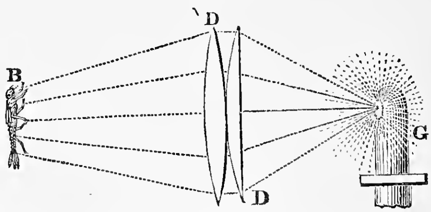
condenser D, the latter might be wholly dispensed with: this, doubtless, would be the simplest method of illuminating opaque objects, and at the same time would possess the additional advantage of exemption from refrangibility. But since, in practice, it is not advisable to construct a solar microscope that will not exhibit transparent as well as opaque objects, and since the condensing lens conduces effectually towards illuminating them both, it would be a wasteful expense to make the reflector of such large dimensions.

ILLUMINATION FOR GAS MICROSCOPES.

It has been assumed (which, however, is notstrictly true, although sufficiently so for practical uses), that the rays of light emitted from the sun are parallel to each other, and that it belongs therefore to the illuminating portion of the solar microscope merely to divert them from their parallel course, and make them converge toward the object intended to be illuminated. In the case now under consideration, the rays emanating from an artificial light placed at a short distance from the condenser are divergent, and all except the central ones fall obliquely upon the surface of the lens; hence a double operation must be performed upon them before they can be made, as in the former instance, to converge upon the object interposed for illumination: that is to say, it is necessary first to bring them parallel, and then, as in the instance of the solar, to converge them toward the object they are intended to illuminate. This, however, may be effected, as we shall presently see, with a single reflector also. In both cases the main object to be attained is to collect the greatest possible number of rays that can be taken up; to accomplish which with a lens, the surface next the light should be concave, or at least a plano, otherwise the rays nearest its margin will, owing to their great obliquity, be reflected from and not refracted

through it. From the numerous experiments I have made in constructing gas microscopes, I find the best arrangement for the illuminating part, when lenses are employed, to be similar to that shewn in figure 12; where a plano-convex lens, D, is

FIG. 12.



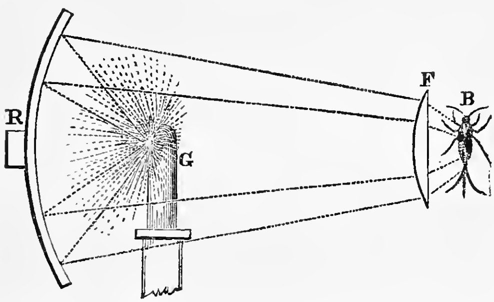
first placed with its flat surface next the light, G, and at such a distance from it as to bring the divergent rays nearly parallel; and then, in close connexion with it, a double convex lens, 'D, to condense them upon the object, B. In some instances I have used three plano-convex lenses, but I do not think the advantage obtained by thus dividing the refractions at the surfaces compensates for the loss sustained by the introduction of an extra lens*. The contrivance given at figure 12 answers so completely that it leaves little room for any improvement to be effected by a combination of lenses, an angle of light of between 50 and 60 degrees being taken up.

In order to increase the quantity of light, it has been proposed to place a reflector behind it, but this cannot be made to produce the desired effect unless its centre of curvature coincides with the radiant; for the reflected rays not having the same divergence as those proceeding direct to the lens from the light itself, cannot be taken up so as to afford any additional advantage in the illumination. If, however, a simple

* In cases where the diameters of the condensing lenses are great, and the focus short, it might be an improvement to use fluid lenses; or even, in some cases, Sir D. Brewster's polygonal lenses might be serviceable.

concave reflector properly constructed be used without any lenses, the result will be quite equal, if not superior, to that obtained by the preceding management, and at the same time will obviate one of the greatest defects there is to contend with, viz. that arising from refrangibility. This construction is given at figure 13, where R is the reflector, G the ignited lime, and

Fig. 13.



B the object: a field lens, F, is introduced in the diagram, and might be useful in some cases.

In gas microscopes constructed as above, with only a reflector for illumination, on removing the magnifiers in front the illuminated portion of the screen will not be a complete circle, the lime, jets, &c. interposing between the two, shewing their shadow upon it. I am informed by a person who has experimented with a reflector in this way, that we cannot obtain so great a range of distance between the screen and instrument as when lenses are used, so that a certain radius of curvature is suited to one distance only: of this circumstance I am unacquainted, not having observed it when making my experiments about four years ago.

Before proceeding to the consideration of the illumination of opaque objects, it will be advisable to introduce a few remarks on the above.

It has been stated in the Microscopic Cabinet, that objects

are best defined when viewed by diverging rays. In the solar microscope this is difficult to accomplish, but it will be seen that in the gas microscopes we have divergent rays; and I have little doubt but for large objects it would be a vast improvement to introduce them close to the condensing lens, on the side next the light. This arrangement would have the advantage of enabling us to reduce their diameter—a point of no small importance, as the thickness of glass in large deep lenses is considerable, and the loss of light appreciable.

In the solar microscope, the Rev. J. B. Reade has recently introduced astronomical slides, and those of the phantasmagoria, between the large reflector and condensing lens, with effect; and indeed all the best instruments of that kind should be provided with the means of such adaptation.

I cannot omit to notice a remarkable error which is to be found in all the optical treatises from Gravesande's down to those of the present day, respecting the construction of the phantasmagoria and magic-lanthorn. In all of these, the slide containing the figures to be projected on the screen is described and drawn as placed between the plano-convex bull's-eye condenser and the magnifier—that is to say, in converging rays, whereas, in practice, the slide is placed next the light, and close behind the bull's-eye, so that in fact they are in diverging rays, and the bull's-eye condenser and magnifier act as a doublet, and the distortion arising from the sphericity of the condenser is thus greatly diminished.

In my lucernal microscope, where a moderately magnified picture of the object is thrown upon a plate of greyed glass, for drawing its outline, &c., or for enabling several persons to view it at the same time, the principle of the optical construction which I adopt is similar.

Opaque Objects.

The simplest method of illuminating opaque objects in gas microscopes is by means of a concave reflector only, as shewn

in fig. 13; in which case, however, the object and the light, B and G, are required to change places, and the reflector must be provided with a sufficient aperture in its centre to admit of the rays of light proceeding freely from the object toward the magnifier behind it. By inspecting this figure with the alteration proposed, it will be manifest that the cone of rays incident upon the mirror will of necessity be very small, and consequently that large objects only can be sufficiently illuminated by it.

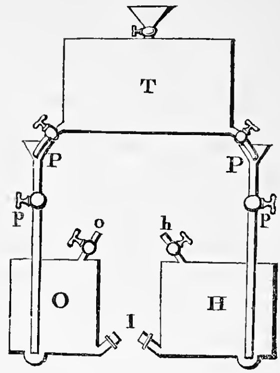
Another mode is to receive the rays at B, (fig. 12) upon a concave reflector, similar to that represented in fig. 11; but it may be remarked, that in no instance has it been practicable to introduce, for displaying opaque objects, magnifiers of equal powers with those used for transparent ones, and solely on account of a deficiency in the illumination.

Though the description of an apparatus answerable for the purposes of containing the gases and regulating a due supply of them for combustion, should in strictness fall within the province of the chemist rather than the optician, still, as the subject seems to be almost naturally brought under our consideration, a few observations respecting it will contribute, I think, towards rendering this tract so much the more complete. Before I proceed, therefore, with the rules necessary to be observed in the management of the instruments themselves, I shall take this opportunity of stating some particulars as to the regulation of the gases. It is scarcely requisite to mention the propriety of having every part of a gas apparatus, together with all the pipes, stop-cocks, joints, &c. used in connexion with it, perfectly air-tight, both as far as safety is concerned, and to prevent the waste and loss of a valuable commodity.

Fig. 14 exhibits the form of an apparatus suitable for the purpose. O and H are two cylindrical vessels of sufficient capacity to contain gases for one or more representations; P P are two pipes, with stop-cocks at *p p*, and apertures to admit of their discharging themselves into the bottom of the

vessels O and H; T represents a tank or reservoir of water, to

FIG. 14.



supply an uniform pressure or force to expel the gases from the vessels; *o* and *h* are exit pipes fitted to communicate with the jet, where the ignition is to take place. The action of this apparatus is as follows: the vessels, O and H, being filled with the gases, and the closed tank, T, with water, the pipes *o* and *h* are to be attached by means of union-joints to the feeding pipes of the jet. If the stop-cocks of the tank are now opened, the funnels at P P will be filled with water, on the principle of the common bird fountain; the lower cocks, at *p p*, may then be opened, when the water issuing from the apertures at the bottom of the pipes will ascend in the vessels, and so compress the gas that it will exert itself to escape. The pressure of the water against the under surface of the gas will be equal to that of a column of water of the height of the water in the funnel above that to which it can ascend in the vessel; the pipes, P P, must therefore be of sufficient length, viz. 20 to 30 inches, to admit of the pressure overcoming the resistance occasioned by the gas passing through the tubes, and to discharge it from the mouth of the jet with sufficient

force against a body of lime prepared for combustion.* The stop-cock at h may now be opened, and the hydrogen gas issuing from a proper aperture in the jet must then be inflamed. In like manner, the stop-cock at o being turned, a due supply of the oxygen will also be furnished.

The mode of filling the vessels with the gases may be thus explained: the stop-cocks at o h and P P being opened, the water from the tank will flow freely into the vessels O and H; as soon, then, as they are filled, let all the stop-cocks be closed. The caps of the induction orifices or shallow tubes situated at I, should next be unscrewed, and the extremity of the small pipe through which the gas is to pass inserted at the induction orifice: as the gas rises to the top of the vessel, and there displaces the water, the latter will continue to flow out at I, until the vessel is filled with gas, when, the caps being screwed on tightly, the apparatus will be ready for use.

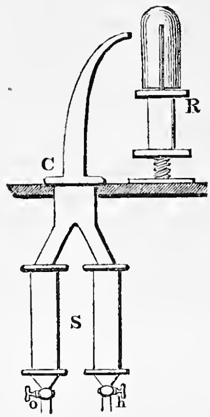
I would here remark, that each of the vessels should be furnished with a glass gauge-pipe, communicating with the interior, for the purpose of indicating the quantity of gas in the vessel, and how much is consumed in a given time. It may also be stated, that if there be no gas in the vessels or feeding tubes, the water will be liable to be expelled from the jet, destroying the lime, and otherwise damaging the apparatus. The tank should be constantly filled with water, which may readily be done, whilst the lower cocks are closed by means of the funnel at the top. The great advantage, however, of my closed tank over an open cistern is, that the pressure upon the gases is regulated by the length of the pipes, P P, without any reference to the variable height of the water in the tank. This is a point of vast importance, inasmuch as the intensity and steadiness of the light will depend entirely upon an uniform

* It will be found in practice much better to employ only one funnel and stop-cock to the tank, T, and make the pipe, P, branch off to each vessel: I have recently learnt that Mr. Maugham has proposed the latter plan, but in place of the tank, T, he uses a ball-cock to regulate the supply of water.

pressure: with a varying pressure the brilliancy of the image on the screen will be continually varying also.

Fig. 15 illustrates a method of constructing the jet, and how

FIG. 15.



the lime is disposed for combustion: *o* and *h* represent the feeding-pipes of the jet, which are to be attached to the corresponding tubes of the vessels O and H, designated by the same letters. At S are situated two of Hemming's safety-tubes, containing bundles of fine copper wire, gauze, or asbestos, to cool the gases, and prevent explosion, should any accident occasion the ignited gas to return towards the vessels. When speaking of the *return* of the gases in the direction of the vessels, and thus forming in the tubes, or vessels themselves, an highly explosive mixture, there is one point to which I have not yet alluded, but which I conceive to be of the greatest possible importance; and it is this—viz. that the areas of the bases of the vessels H and O should bear exactly the same proportion to one another as that in which the hydrogen and oxygen gases, in reference to volume, are required to be used for consumption. The necessity of this will be sufficiently manifest, since more than twice the quantity of hydrogen to that of oxygen is expended in producing

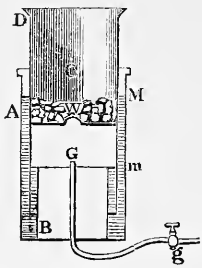
the requisite light. Whilst the gases are being consumed, their under surfaces, in the vessels H and O, by the proposed arrangement will be continually kept at equal altitudes ; and since the water ascends to these under surfaces, and the pressure there exerted is dependent upon these altitudes, as before mentioned, the pressure in both vessels will remain uniformly the same. By admitting, therefore, twice as much hydrogen as oxygen to pass through the stop-cocks of the feeding-pipes of the jet, the two gases, in their due proportion, will arrive at the mixing-chamber, C, pressed forward by equal forces; nor will there be any disposition in the one to overcome the force of the other, and thus to repel the mixed gas from the chamber, C, back into either of the vessels, but it will proceed steadily on to the mouth of the jet, and so much of the gases only will be admitted to mix as can be contained in the *small* chamber at C. R represents the rod upon which the lime, in the form either of a sphere or cylinder, is sustained—(the latter form for ordinary uses is generally preferred.) In either shape the lime, by means of clock-work, or the hand, should be made to revolve, and thus present a new surface to the ignited gas, otherwise it will be liable to burn away unequally, and to burst. The lime cylinder is sometimes placed horizontally, and the flame brought to play upon its base ; but this arrangement does not afford so steady a light, and a cavity being soon produced by the combustion, a strong shadow will be thrown upon the screen.

I next proceed to describe an apparatus of a different construction, and possessing the immense advantage over the other of requiring but a comparatively small quantity of water for its use. I conceived the plan of this from reading an account of one constructed in Turkey, on a similar principle, by Mr. W. H. Barlow.* Mine differs from that gentleman's, however, in two material respects : 1st, I am enabled to dispense with a vast proportion of the water requisite for his apparatus ; and, 2dly, by substituting weights in the place of water, I give it

* See Phil. Mag. vol. viii. p. 240, 3d Series.

additional steadiness, by bringing down the centre of flotation to a much less elevated point. Let A, fig. 16, be a section of

FIG. 16.



a cylindrical vessel composed of copper or tin, and connected at the bottom to a small cylinder in the situation of B. A third cylinder, D, of equal length with A, and about three inches less in diameter, is so placed within the vessel A that it can be moved up and down with perfect freedom, and admit of a small quantity of water being contained between its outer surface and the inner surface of A. The cylinder D is furnished with a diaphragm, situated at such a distance from its lower extremity that when D shall descend to the bottom of the vessel A, the diaphragm may coincide with the upper extremity of the cylinder B. The cavity represented at B will be of nearly the same dimensions as are required in the vessel D, to contain a volume of gas sufficient for a specified time. The operation of this apparatus is as follows: a small quantity of water is poured into the vessel A, and D is then inserted into it. The stop-cock at *g* being opened, as the diaphragm and cylinder D descend to B, the atmospheric air issuing through the orifice at G will pass along the pipe, and make its escape at *g*. If the gas be now admitted at *g*, it will occasion the floating vessel, D, to ascend in A, until the space G is taken up by the quantity of gas required. The stop-cock, *g*, may then be closed, and the water in the vessels will stand at the same level, *m*, within and without the floating

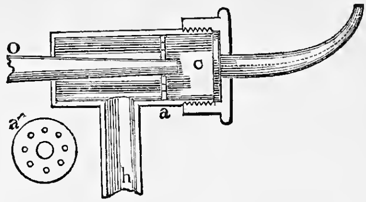
vessel, D. If weights are now placed at W, in the cylinder D, and additional water be poured into the vessel A, it will rise on the outside above *m* to some height, M, to be determined by the requisite amount of pressure. On opening the stop-cock, an uniform supply of gas will then be discharged at *g*, and as the cylinder D descends, the water will remain constant at the levels M and *m*. When it is necessary to replenish the vessel with gas, the weights at W must be removed by the hand, or otherwise, and the operation conducted in the order previously described. In Mr. Barlow's apparatus, the spaces represented at B and W, the part of D situated above its diaphragm, are occupied with water, which, in case of leakage, may be exceedingly troublesome, and must be always inconvenient, from the necessity of removing the whole of that contained in D, whenever the vessel is to be refilled with gas. Further, in order to obtain the requisite pressure with water, the portion of D over the diaphragm must be nearly filled with it, when its centre of gravity will be somewhere at C; but in the case of weights, when sand, stone, or metal of greater specific gravity than water, is used, the centre of gravity will be somewhere at W, which being below M will render the flotation far more steady than if it were above it, at C.

Since the gases must be kept apart from each other, the like construction will be required for the use of each; and the cylindrical vessels of the two apparatus being made of the same elevation, should be so proportioned with respect to their diameters, that the same height of gas may be consumed from the one as from the other in a given time.

The description of jet used by Mr. Barlow is shewn at fig. 17: it is commonly known as Daniell's jet. It consists of two tubes, *a* and O, the one inserted within the other, in the manner represented by the figure. The outer tube (*a*) has a diaphragm situated at *a*, through which a portion of the inner tube (*o*) is admitted into a mixing chamber at *c*. This diaphragm is perforated with small holes, to allow the hydrogen gas to pass from the feeding-pipe (*h*) through the holes *a* into the chamber,

c; and that portion of the tube O situated within the chamber,

Fig. 17.



c, is perforated also, to admit the oxygen from the tube O to mix with the hydrogen in the chamber, *c*, and, in that condition, to proceed to the mouth of the jet. I prefer this arrangement to the one given at fig. 15, because it is not so liable to be injured, should any water, as will sometimes unavoidably happen, be forced through the pipes into the jet. As the gases burn much better when dry, it might be desirable to pass them through a vessel containing anhydrous muriate of lime, to free them from moisture.

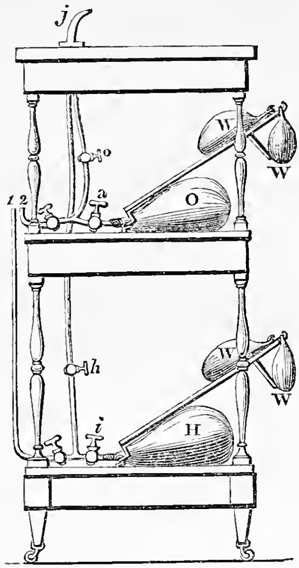
I shall now describe a portable apparatus, in which the gases are contained in bladders, or bags made of cloth or leather, rendered air-tight by a coating of caoutchouc; and the pressure is managed entirely without water, by the application of sand-bags or weights*.

Figure 18 represents a side view of the apparatus. It consists of a square frame of wood, running on castors, and furnished with horizontal partitions or shelves upon which the bags or bladders, O and H, containing the gases, are to be placed; the upper shelf being usually preferred for the oxygen gas, in order that the stop-cock at *o* may be the more readily adjusted, and the lower shelf for the hydrogen. Small pipes, with stop-cocks, as shewn at *o*, *a*, *i*, and *h*, are annexed to the different bladders, and made to communicate with the jet, J. On the upper shelf stands a purifier, hereafter to be described,

* Hydrogen being transmissible through most bodies, the bags or bladders should not be filled until wanted for use.

for freeing the gases of their impurities, so that, without passing through any other intermediate vessels, they may, as soon as generated, be conveyed at once into the bladders, O or H, to

FIG. 18.

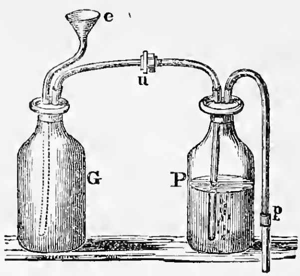


be used when requrired. W W are the weights, or sand-bags, pressing, by means of inclined boards, upon the distended bladders, and thus, in conjunction with the stop-cocks, acting as regulators for the steady and proportionate supply of the gases. It is scarcely worth mentioning that, during the time the bladders are being filled, the weights and boards must be of course removed*.

* The method by which the pressure on the gases is obtained in the apparatus figure 18, has been objected to, as it varies with the inclination of the boards to which the weights are attached: to remedy this inconvenience, the gas-holders might be constructed similar to the *receivers* of organ-bellows. See Edinburgh Encyclopædia, vol. xv. p. 676, plate 447, figs. 5 and 7.

The addition of a few words more on the practical method of generating and purifying the requisite gases, will, I think, be in strict conformity with the design of the present tract, and suffice to render this part of the subject tolerably intelligible to the generality of readers, It has been already noticed, that a bottle, termed a purifier, is placed, for convenience sake only, on the stand at P ; and, on the other side of it, not discernible at a side view, is stowed a leaden bottle also, adapted for the purpose of generating the hydrogen gas. Fig. 19 represents

Fig. 19.



these two bottles, taken from their respective situations, and now supposed to be employed in the order they are exhibited. Some water and granulated zinc are first put into the leaden generator, G, (about a pint of water and a pound of zinc will be sufficient,) and the purifier, P, is about two-thirds filled with water. The bottles are then securely corked, and a communication is established between them by tubes perforating the corks, and brought into connexion with each other by an union-joint at *u*. In like manner the tube at *p* is made to communicate successively with the pipe, 1 or 2, of the several bladders intended for use. If a small quantity of sulphuric acid (about half a wine-glassful) be now poured into the funnel at *c*, a portion of the water will be decomposed, and the hydrogen gas speedily evolved, and pass through the purifier into the bladder or bags, H: when the evolution becomes languid, fresh acid

may from time to time be added, until the needful supply of gas is obtained*.

The mode of generating and purifying the oxygen gas is extremely simple, and may be very summarily explained. If an iron retort partly filled with lump manganese be inserted into a strong fire, as soon as the manganese attains to a red heat it will part freely with the oxygen it contains; and if a communication be made between the retort and the purifier, P, by means of a long tube, the oxygen will pass over into the purifier, through 2 and *a*, into the bladders at O, in the manner before described for the hydrogen. Thus the same purifier will serve for both gases: too much care, however, cannot be taken to retain the gases quite separate from each other, and not to risk the possibility of an explosion. I would caution also against the purifier being more than two-thirds filled with water, lest any of the water should be conveyed to the bladders and destroy them. The quantity of oxygen that can be contained in the bladders suited for the apparatus I have now described will sustain a light for one hour; that of the hydrogen for about half that time; but since the latter can be very readily procured, little, if any, delay will be thereby occasioned.

ON THE MANAGEMENT OF SOLAR AND GAS MICROSCOPES.

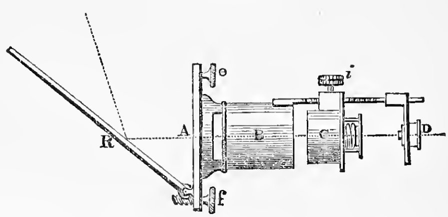
In selecting a room for a solar microscope, the first consideration should be, that the aspect be towards the south, so that from the window, in fine weather, you may command a view of the sun for the greater portion of the day. This room must be provided with the appropriate white screen, constructed on the wall immediately opposite the window; ex-

* The apparatus, figure 18, would be found useful for many chemical experiments, and especially for exhibiting the combustion of metals by the mixed gases.

cepting which, every other part, ceiling, walls, &c. should be rendered, as before mentioned, as dark and sombre as possible. On this arrangement, and the brilliancy of the day, will very much depend the beauty of the representation. The size of the room should be in a great measure regulated by the nature of the exhibition: where many persons are to assemble, it should be well ventilated and large; and in no case should the distance from the window to the screen be less than ten or fourteen feet, as this will have much to do in determining the extent of the illuminated disc upon which the image is to be thrown, and the magnitude of the image itself. The diameter of the disc should be about one half the distance between the window and the screen. The window must be closely fitted with a firm shutter or board, in the centre of which must be cut an aperture suitable for the reception of the instrument: thus all the light will be excluded but that which is to pass through the instrument and illuminate the screen. If, however, the shutter be furnished with an additional opening, which may be readily closed when necessary, it will be found extremely convenient for the purposes of ascertaining the position of the clouds, the state of the weather, &c.

Figure 20 represents the external appearance of a solar

Fig. 20.



microscope:—A, a side view of a square metal plate, which is to be firmly fixed to a window shutter; B, the tube containing the condensing lens: between this lens and the plate, A, is an aperture for the admission of large phantasmagoria and other slides; near the end of the tube is attached a bar, with a rack

for carrying the slider-holder and magnifiers; C, the said slider-holder, with its field-lens; and D the arm for holding the magnifiers; R is a plane mirror, which is exposed to the sun, and capable of being adjusted to its azimuth and altitude by means of the milled heads, *e* and *f*.

This adjustment requires adroitness, in order to keep pace with the varying position of the sun: the great object of it is that the sun's rays may be reflected from the mirror directly along the axis of the instrument, so as to form, after passing through the condensing lens, a circular disc upon the screen: when this is obtained, it will be a certain test that the adjustment of the reflector is correct. Some little care is requisite, in showery weather, that the reflector be not injured from becoming wet. At a convenient distance should be stationed a suitable table, or shelves, for containing the various parts of the apparatus, vessels containing objects, &c. which should be disposed in such order that they may come to hand readily in the dark. If, however, it can be easily obtained, a small inclosure, just sufficient for one person to manage the instrument, will be found of great advantage. This may be fitted up with every convenience, and a little light being admitted into it will not affect the appearance in the room itself. If the magnifier be now inserted into the tube D, and the arm moved backwards or forwards until the disc be entirely illuminated, the object may then be placed within the slider-holder, C, and adjusted to the magnifier at D, and thus a distinct image, or picture of it, will be thrown on the screen.*

The sliders for inclosing the various living objects must be kept clean and dry; and all the objects, whether animate or inanimate, should be carefully arranged in the order they are to be viewed. A few small white basins or saucers, with some

* I am informed by the Rev. J. B. Reade, that it is preferable to place the field-lens beyond the focus of the condenser, by which means the intense heat produced at that point is avoided, and the objects or magnifiers preserved from injury. Mr. Reade has had so much practice with the solar microscope that his opinion is valuable.

feathers, &c. for transferring the living objects into the sliders, will be useful. For a few minutes previous to the exhibition, the room should be retained in total darkness; or if a little light be necessary, it should be supplied from a *common* lamp; the reasons for which are these: in darkness the pupil of the eye dilates, and becomes capable of discerning the minutiæ of objects with greater facility and exactness; and the dull yellow flame from a common lamp, by its contrast with the resplendent whiteness of the sun's light, serves but to heighten the effect.

The selection of objects should greatly depend upon the taste of the company to whom they are to be shown. When amusement and general instruction are principally aimed at, large living objects, such as aquatic larvæ,* &c. will answer the purpose very well; also the splendid wings of foreign butterflies; thin sections of fossil woods, charcoal, jet; the circulation in animals and plants; solutions of salts made to crystallize by evaporation: and silver from a state of solution precipitated upon small pieces of copper wire, thus forming what is called the silver tree;—all these will prove highly interesting when viewed under the miscroscope. And if to these be added the various manufactured fabrics, such as lace, blond, muslin, and the like, and the contrast displayed between them and the transverse sections of different woods, plants, &c., I know of no exhibitions that will serve better to elucidate the perfection and pre-eminence of Nature's structures over the most ingenious contrivances of art, and to engraft upon the youthful mind impressions, not soon to be obliterated, of the Almighty hand that created them.

To the more scientific observer, objects in detail will be of deep interest: for instance, the proboscis of the fly, its feet, &c.; the lancets of some insects; the tongue of the bee; the singular and delicate forms of the different infusoria, and the arrangement of their internal organization; the markings on

* See Microscopic Illustrations.

the scales of butterflies, moths, &c.; sections of fossil woods, and longitudinal sections of woods of recent growth: in short, myriads of specimens may be procured, both of vegetable and animal structures, accommodated to the intellect of every human being, and calculated to advance the most profound philosopher a step onward in the great path he is journeying, toward comprehending, as far as the mind of man can comprehend, the immensity, beauty, design, and order of God's works.

As much, however, will necessarily depend upon the selection of magnifiers suitable for particular objects, it is advisable to arrange the objects according to their size, commencing with the greater ones, which require only shallow magnifiers, and gradually proceeding to those which are to be viewed with the deepest powers. Notwithstanding, it will leave a good impression, ordinarily, to conclude with representing a collection of large living objects under the lowest power of the instrument. Whilst changing the object or slider, a screen should be placed before the instrument for the purpose of excluding the extra light which would be otherwise admitted, and tend in a great degree to destroy the effect, by causing the pupil of the eye to contract.

Although the preceding remarks may seem to refer especially to the solar microscope, still, as both that instrument and the oxy-hydrogen gas microscope resemble each other so very closely in most particulars relating to management, it would be almost a repetition of words to give them, in this respect, a distinct consideration. If, then, we substitute the regulation of the gases, the adjustment of light as to distance from the condenser, and the arrangement of the lime-ball, or cylinder, for the employment of the sun's light by means of the plane reflector, little more will remain to be said upon the subject. As very much of the effect will always depend upon the qualities of the lime, I would recommend the trial to be made of all the various descriptions of lime that can be easily procured; and after they have been well baked, let that be selected which,

without bursting, affords the steadiest and most brilliant light. In putting the gas apparatus into action, the hydrogen should be turned on first, and the light instantly applied to it; after which, by a due supply of oxygen, the dull bluish-red flame will gradually change its character until the lime situated near the mouth of the jet shall become entirely ignited, when it will be succeeded by an exceedingly intense white light. If too much oxygen be admitted, the light will be totally extinguished. A very little experience, however, with some attention, will enable any one to form a true judgment as to the correct proportions.

I shall conclude this little treatise by appending a few cursory observations.—The solar microscope is admirably adapted for tracing with a pencil a magnified likeness of any minute object, which may be done with great facility and precision by placing a sheet of white paper in front of the screen, and throwing the image directly upon it. The exact proportions of the different parts, and their relative situations, by far the most difficult points to be attained in drawings of this nature, (see Microscopic Illustrations, on this subject,) may thus be achieved by merely the mechanical motion of the hand. When living objects are to be drawn, what are termed angular sliders should be provided, to retain them; for, when placed in these, they will soon, by their restlessness, thrust themselves into situations of restraint well suited for the purpose. This form of slider will also be found extremely convenient for showing the circulation in the water-newt, or any small fish. If the drawing of objects be principally aimed at in the use of the instrument, a small moveable screen, expressly constructed for it, of just sufficient dimensions to take in the projected image, may be interposed between the instrument and the original screen; also, its texture being appropriate, the image will be seen more distinctly behind the small screen than in the front of it, in which position there will arise no obstruction to the drawing, from the shadow of the hand.

EXPERIMENTS ON THE POLARIZATION OF LIGHT WITH THE SOLAR OR GAS MICROSCOPES.

In most of the different arrangements for viewing the wonderful and oftentimes beautiful phenomena displayed by various bodies, when submitted to the action of polarized light, the quantity of light which can be obtained is so extremely small, that very faint impressions consequently result from it. In solar and gas microscopes, where an abundance of light is readily supplied, all these properties may be exhibited with exceeding brilliancy; for which purpose a slider must be so contrived, that the crystal, or other bodies to be examined, may be placed between two plates of tourmalines, or two single image calc prisms, bundles of glass plates, &c.

When a transparent object is placed in the solar or gas microscope, the illuminated disc, upon which the image is viewed, is made up not only of the light which is transmitted through the object itself, but of that portion also which, not having come into contact with it, passes more freely through the instrument. This extraneous light, in cases where a delicate object is exhibited, has so great a tendency to subdue the image, that but a very faint impression of it is produced upon the screen. Opaque objects, the representations of which are seen entirely by the light reflected from them without the interruption of any extraneous light, have all their beautiful markings and colours displayed in the greatest possible perfection. From the intense heat, however, always accompanying the condensation of solar rays, very minute objects are liable to be too seriously injured (if not absolutely burnt up) to be risked in solar or gas microscopes: those of moderate size, therefore, are necessarily used, many of which, such as small flowers, shells, &c., and the *basso relievo* on medals, will be found to be highly interesting.

In exhibiting the internal structure, circulation, pulsation, and peristaltic motion of the alimentary canal and other organs of aquatic larvæ, &c., * specimens should be selected immediately subsequent to the shedding of their skins, in which condition the exterior covering is much thinner and more transparent than at any other period of their existence. If the same living objects are to be preserved for a second use, care must be taken that they be provided, on being removed from the instrument, with fresh water of a temperature not much below that of the water which is contained in the slider; for, by suddenly immersing them in cold water after they have been heated by the sun, you would inevitably destroy them.

If the carnivorous aquatic larvæ of insects be kept hungry in clear water for a short time previous to their being viewed, and then provided with appropriate food, or, in its absence, with the eels found in sour paste, for which they have a relish, their peculiar mode of satisfying their voracious appetites will be a subject of curious examination. The eels in paste, and many of the infusoria, are often so exceedingly crowded in the vessels that contain them, that additional clear water is absolutely necessary before you can obtain a distinct representation of them. This operation will be performed with good effect whilst they are under the instrument; or, what perhaps may be more convenient, let a slider furnished with a due quantity of clear water be first placed within its holder, and then add a drop of the infusion including the animalcules.

Among aquatic larvæ, the most beautiful and delicate are those of the numerous species of gnat, but more especially that of the straw-coloured one (*Chironomus plumosus*) described and drawn in the Microscopic Illustrations; the larva of some May flies, such as that of the *Ephemera marginata,* given in the same work. For these creatures a deep vessel or slider should

* The "Microscopic Cabinet" and "Illustrations" contain descriptions and drawings of avariety of the most choice living objects for these instruments.

be obtained, and the instrument should admit of it moving upwards and downwards, as they rise occasionally for respiration.

I have just hinted at the disadvantageous consequences, in reference to the use of these instruments, resulting from the association of heat and light; in short, that numerous objects would be totally destroyed, if subjected to that intensity of heat which universally accompanies the acquisition of a sufficiency of light for illuminating solar and gas microscopes.* The inference to be drawn from this consideration is, that these two instruments are necessarily much restricted in their use, because, requiring, as they certainly do, a far more powerful light than other microscopes in order to give an equal effect, a multiplicity of objects in every way adapted to other instruments are thereby wholly excluded from them. To do away with this obstruction to extending the power of these microscopes to their utmost capability, I have interposed transparent media between the condensed light and the objects, such as a large slide, filled with clear water, placed immediately behind another containing delicate living objects, and thereby in a great degree reduced the heat. It appears, however, from the valuable experiments recently made by M. Melloni "*On the free transmission of radiant heat through different solid and liquid bodies*,"† that heat and light may be separated to a very great extent; for some bodies, while they transmit nearly all the heat, do not transmit any light; and for our purposes there are several diaphanous substances which transmit very little heat, as alum, the salts of soda or potash, fluor spar, &c. Thus, out of 100 incident rays, the following pass through the same thicknesses of—

Ice very pure	(diaphanous,	colourless)	6
Sugar melted,	(do.	yellowish)	7

* In the gas microscopes, a plate of mica placed between the light and the first condenser will prevent the latter from breakage by the heat.

† Annales de Chimie et de Physique, t. 53, p. 1, and t. 55, p. 337. Also see an excellent translation in the first part of the Scientific Memoirs.

Alum,	. . . . .	9
Citric Acid,	. . (colourless)	11
Gum, .	(diaphanous, yellowish)	18
White topaz,	(do. colourless)	33
Glass,	(do. do.)	39
Fluate of lime,	(do. greenish)	46
Rock salt	(do. colourless)	92

A. P.

CHAPTER IX.

I.—*On Cuvier's Method of Dissecting Microscopic Subjects under Fluid; with Additions.*

II.—*On a new Method of obtaining a delicate Adjustment to the Focus of Microscopes.*

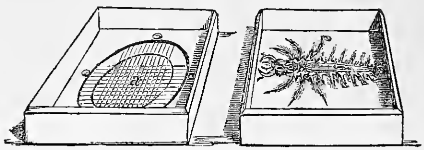
III.—*On an improved Mode of Supporting a Candle or Lamp for Microscopes.*

I.—CUVIER'S METHOD OF DISSECTING MICROSCOPIC SUBJECTS IN FLUIDS, WITH ADDITIONS.

BEING requested some years ago to make a dissecting apparatus to a microscope, similar to that usually employed by CUVIER, which consists of a metallic trough, similar to fig. 22, it occurred to me that for many purposes, where the subject under dissection was not quite opaque, a glass bottom to the trough would be an improvement, and accordingly I made some, and have found them very useful, as sufficient transmitted light is often obtained. The addition also of coarse micrometer lines, cut on the disc of glass, renders it more complete. One of these troughs is shown at fig. 21: they are attached by a bayonet-joint to the common stage, or fit

into the moveable one at *o*, fig. 1, plate 1, and can thus be turned in any direction.

Fig. 21. Fig. 22.



M. le Baron Cuvier's method of using these troughs is as follows :—Take a composition of bees'-wax and Venice turpentine, or Canada balsam, and line the trough with it while warm; then lay in the subject to be dissected, first having dried the parts that are intended to be fixed to the composition, and when the whole is cold, the dissection may be commenced, the trough being first filled with water*.

By fixing a subject in this manner its parts are more readily separated, and being covered with a fluid, the adventitious portions are easily washed away with a camel's hair pencil.

The knives used for dissecting microscopic subjects, are usually made similar to those employed by oculists for operations on the eye, and the scissors, described in the "Cabinet," page 243, are highly useful. When the subjects are minute, I have found a great advantage in having the small cutting instruments fitted into handles, in which their lengths and consequent elasticity can be varied, and for these handles,

* Microscopic dissections are of great value; they are now beginning to be appreciated, and ought to be encouraged. It is impossible to determine, with accuracy, the organization and functions of the smaller tribes of animals and vegetables (which, from their numbers, often produce serious consequences to man), without careful dissection of them. In my humble opinion, it is to be regretted that the Society of Arts, in place of rewarding Cuvier's troughs, which are not new, had not rewarded the candidate for his industry and patience in making microscopic dissections, and thus have directly promoted this valuable and important branch of natural history.

needles of various kinds, especially the leather-workers', when ground on a fine hone, afford very useful instruments for dissections.

II.—ON A NEW AND SIMPLE METHOD OF OBTAINING A DELICATE ADJUSTMENT OF THE FOCI OF MICROSCOPES.

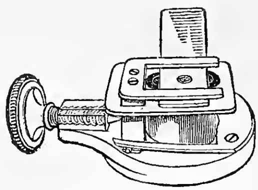
In Chapter XV. of the Microscopic Cabinet, I have described the various methods by which the adjustment of the focus of microscopes is effected; such as the rack-and-pinion, the screw, the bent lever, and the excentric*, with their various advantages and defects. I have also minutely described a plan of mine, by which a coarse and fine movement may be readily obtained. This is the primary object to be accomplished. Now although that method is unobjectionable for the microscope, where single lenses or doublets are used, yet it is not so when applied to an engiscope (that is, compound microscope), the size and weight of the body to be moved rendering it unsteady. To remedy this defect, various ingenious contrivances have been devised, retaining the rack-and-pinion movement, for coarse adjustment, and applying the finer one to the stage which carries the object. All these methods, however, where the desired effect has been obtained, have been so complex, that it is not likely they will come into general use. Under these circumstances I was led to construct the following, which it is not probable will be surpassed in simplicity or effectiveness, and, what is of great importance, cannot be easily deranged. Figure 23 is a perspective view of it.

It consists of a plate attached to the stage of the instrument: on this plate is fixed a socket for holding a fine steel screw with a conical point, which latter acting against a block

* See Treatise on Optical Instruments, p. 36, fig. 36.

carrying the object held in a safety slider-holder, is forced upwards by the conical end of the screw acting as an inclined plane, while a spring is so arranged as to keep it down to its bearing. The milled-head of the screw, if required, might be divided, by which means the elevation or depression would become a measured quantity.

FIG. 23.



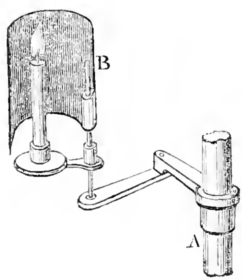
III.—ON AN IMPROVED MODE OF SUPPORTING A CANDLE OR LAMP FOR MICROSCOPES.

Observers with the microscope are fully aware of the importance of the proper illumination necessary to make that instrument produce the best effect: much depends upon the direction of the illuminating source, and when once properly arranged, any accidental alteration destroys the effect, and the whole must be commenced afresh. From these considerations I have been induced to attach the holder for carrying the candle or lamp to the stand of the instrument, as shown in the sketch below, by which the not unfrequent movement of the instrument, especially when more than one person is observing, will not affect the direction of the illumination, as all will move together. I am convinced those who have much employed a microscope will appreciate this trifling improvement, and approve of its introduction in this work.

A is the stem of the stand of a microscope; on this the socket slides to the required elevation, and the arms allow of the light being placed in any direction. B is a shade, to take off the direct light from the observer.

A. P.

Fig. 24.



APPENDIX.

No. 1.

ON MAKING DRAWINGS OF MICROSCOPIC SUBJECTS;

In a Letter, *by FRANCIS BAUER, Esq. F.R.S. F.L.S. &c. &c.*

Dear Sir,

I feel great pleasure in complying with your request, by explaining my method of making correct magnified drawings with microscopes. I often wished to have an opportunity to publish such an account; and I think your forthcoming "Micrographia" would certainly be the most proper for promulgating such a useful subject.

The requisite apparatus for ascertaining with a microscope the correct dimensions and proportions of any minute object, are two glass micrometers, each of forty divisions to an inch, and crossed or squared over their whole surface, similar to those you made for me. One of them ought to be pretty sharply engraven, on a very thin and clear plate of glass: this micrometer is fitted into the eye-piece in the focus of the eye-lens; the other micrometer, which is used on the stage, ought

to be very strongly engraven, and its lines well blackened, that they might be distinctly seen when viewed through the micrometer in the eye-piece. When my microscope was thus armed and adjusted, I ascertained the acting magnifying powers of its objective lenses, which is effected by placing the stronger engraved micrometer on the stage, and viewing and carefully observing, through the micrometer in the eye-piece, how many divisions are occupied by one division, or fortieth part of an inch of the micrometer on the stage: I found that with the objective, No. 2, it occupied precisely ten divisions each way, and consequently divides one linear inch into 400 parts, and one square inch into 160,000 squares.

Having thus ascertained that every division of the micrometer in the eye-piece is equal to a 400th part of an inch on the stage, and every square on that micrometer represents a 1-160,000th part of a square inch, I now retain this adjustment of the microscope permanently, and have no more occasion to use any micrometer on the stage for future operations.

When I wish to make a magnified drawing of a very minute object, I trace on my drawing-paper a number of squares, similar to those on the micrometer, of which each division is an inch (linear), which consequently is 400 times longer than a 400th lineal division on the micrometer in the eye-piece (see fig. 1, plate 3), I then place the minute object, which I wish to measure, on the stage, view it through the squared micrometer in the eye-piece, and move the object on the stage, till it comes into a proper position to be easily examined; that is, till one extremity of the object touches one line of the square on the micrometer in the eye-piece. I then trace on my ruled drawing-paper a correct outline of the object, as in fig. 1, A, B, C, D, E, and find that A is 2½-400th parts of an inch long, and about 1-900th part of an inch in breadth or thickness. B is 2-400th parts of an inch; C, 1-400th; D, 1-800th part: and the three very minute fossil animalcules at E, about 1-1200th of an inch in length, and proportional

in breadth. The globular fungi at F are 1-1600th part of an inch in diameter, and the very minute globules of blood at G are each about 1-2400th or 1-2500th part of an inch in diameter.

Having thus secured correct outlines of all the objects under examination, I finish the drawing by reviewing the objects with another microscope of higher power (perhaps 300 or 400 times,) by which I am enabled to introduce and mark correctly all the minute parts of the objects. All the objects represented at fig. 1 are magnified 400 times linear, and 160,000 times superficial.

I must here remark, that in all my microscopic drawings I have used the English measure.

I must also notice, that in adjusting the microscope for ascertaining its magnifying power, great care must be taken that the lines of the square of the micrometer on the stage exactly join and encompass the lines on the squares on the micrometer in the eye-piece, which is not always the case, or with some objectives the image may perhaps be found to occupy *nine divisions and a fraction,* which would occasion much calculation and trouble to produce a correct drawing*; but this difficulty is easily obviated, when the microscope is constructed with sliding tubes, for by elongating or shortening the tubes, the instrument can be adjusted to the greatest exactness, and on that adjustment depends the correctness of the whole.

When I intend illustrating objects which are larger than 1-40th part of an inch, and would be uselessly increased if magnified 400 times linear, I rule the drawing-paper into squares or divisions of half an inch, and proceed in every respect as in the former case: the drawing thus produced will be magnified 200 times linear, or 40,000 times superficial, (see fig. 2), and again, for drawing larger objects, I make the divisions of my paper of one-fourth of an inch, which

* See Chapter II.

will produce a figure magnified 100 times linear, or 10,000 times superficial, (see fig. 3, plate 3).

When I have wished to investigate and draw large opaque animal substances, such as the inner coats of the stomach, the papillary vessels of the tongue, or the internal structure of the lungs, or the spleen, &c. &c. (all such objects must be examined under water, and cannot be brought under the microscope, and no glass micrometer can be used)—I conceived and used another method, viz., I had several silver plates (of about a square inch, and about the thickness of a shilling), constructed, and in the middle of them regular and accurate square holes or perforations cut out, from half an inch to a 1-10th of an inch linear, (see fig. 4, plate 3.) When I wished to examine such opaque objects under water, I placed one of these plates upon a chosen spot of it, and tracing on my prepared drawing-paper, (divided in squares of the size required); for instance, when a perforation of 1-10th of an inch is employed, I made my squares on the drawing-paper three inches, by which the perforation, and all that is encompassed within it, is magnified thirty times lineally, and 900 times superficially; and tracing and portraying correctly on my paper the image of the perforation, the drawing will be magnified 30 times linear, and 900 times superficial.

I often wished to improve this silver plate micrometer, by dividing, with some fine silver wires, the orifices into smaller divisions; for instance, the quarter part of an inch might easily be divided into four squares, and the half of an inch into sixteen squares, which would greatly facilitate the operation and the production of correct drawings; but I could never meet with any workman who could execute it properly; but I have no doubt you would soon effect this, or any other improvement of this useful instrument. This apparatus should always accompany a complete microscope.

I have now adopted and practised these methods for more than thirty years, and I do not hesitate to state, that, in my

opinion, they are the simplest, the easiest, and perhaps the best, for producing correct magnified microscopic drawings.

I avail myself of this opportunity to acknowledge and correct an error into which I had inadvertently fallen, when (in the year 1816) illustrating the particles or globules of the human blood: I was then provided with very indifferent optical instruments, and stated the diameter of a globule of the human blood to be 1-1000th part of an inch: but on a subsequent investigation, with a somewhat improved apparatus, I corrected that error, and noted the diameter of these globules to be 1-2000th part of an inch; but having since obtained an improved achromatic microscope, and repeated the measurement with that instrument, can now state with certainty, that each of the globules of the human blood is 1-2500th part of an inch in diameter. I am therefore very anxious to give this explanation, as I perceive that my former erroneous statement is still quoted in some recent publications. In the Penny Cyclopædia, Vol. V. page 4, a table of the size of the globules is given. The author concludes his account of the human blood thus:—

"All observers are agreed that the size of these particles, as long as they retain unimpaired the form they possess on escaping from the blood-vessel, is perfectly uniform; but their real magnitude is variously estimated; the size of the red particle of human blood is, according to

Bauer	1-2000	part of an inch.
Wollaston..........	1-5000	do.
Young	1-6060	do.
Kater.............	1-4000	do.
Prevost and Dumas ..	1-4076	do.
Hodgkin and Lister ..	1-3000	do."

This table proves how difficult it is to ascertain that point; but it also proves, that however erroneous my statement of

1-2000th part of an inch then was, it was nearer the truth than the other measurements.

In hopes that the above will prove satisfactory,

I remain, dear Sir,

Most sincerely yours,

Francis Bauer.

Kew-Green, Nov. 1836.

To Andrew Pritchard, Esq.

EXPLANATION OF PLATE III.

Figure I.—A, B, C. D, E, are magnified outlines of Fossil Infusoria, composing Tripoli, which has lately been discovered at Franzenbad, in Bohemia*. F is the outline of four globules or sporules of the fungus *Uredo fœtida,* which produce the disease in wheat, called smut-balls or pepper-brand; and G represents globules of human blood. All the drawings in fig. 1 are magnified 400 times linear, or 160,000 times superficial, so that the real dimensions of the above bodies are easily obtained by a direct measurement of their outline in the drawing.

Figure 2.—A represents the outline of a grain of pollen of the *Passiflora quadrangularis;* and B, a grain of the *Œnothera Lindleyana.* The objects in this figure are magnified 200 times linear, or 40,000 times superficial: that is, each square space represents 1-40000th part of a square inch.

Figure 3.—A is a capsule of fern, *Aspidium trifoliatum;* and B the same, burst open, with its sporules or seed thrown out. These objects are magnified 100 times linear, or 10,000 times superficial.

Figure 4 represents the silver plates, with apertures of different sizes.

* These remains of the Infusoria are the silicious shells of animalcules. Some genera exhibit series of delicate transverse markings: they are best seen as transparent objects, in spirits of wine or Canada balsam. They belong to the division Bacillaria.—See my Natural History of Animalcules, page 59; also § 71 (94), 85, 89, &c.—A. P.

No. 2.

ON

A NEW METHOD OF ILLUMINATING MICROSCOPIC OBJECTS.

By the Rev. J. B. READE, M.A. of Caius College, Cambridge.

In Dr. Goring's valuable Memoir on the Verification of Microscopic Phenomena, it is observed, that "the verification of the real nature, form, and construction, of a vast variety of objects which elude the sense of touch by their extreme minuteness, can only be made out by an attentive study of their appearances, *under a variety of methods of illumination**." The methods of illumination at present adopted are four in number, and consist in the application of *direct* and *oblique reflected light*, and *direct* and *oblique transmitted light*.

The first two methods are applicable to opaque objects, but for the examination of transparent objects all the methods are available. The two latter, however, it is well known, are those most commonly used.

Now, when microscopic objects, not opaque, are viewed with oblique reflected light—the flame of the candle being placed higher than the stage of the instrument, and its light condensed upon the object—it is invariably found that the

* Microscopic Cabinet, p. 183, § 16.

maximum of condensed light which can be obtained by this method is insufficient for the full development of many important characters. If, again, transmitted light, either direct or oblique, be substituted for reflected light, obstacles of a still more serious nature greatly interfere with accurate investigation. Delicate tints are lost; colours naturally bright, or even brilliant, are all but absorbed; the texture and construction of objects are erroneously represented; and, in fact, nothing is seen, in many cases, but a magnified image of the object in mere black and white. Nor is this all; for besides this defective representation, the eye of the observer is always subject to much painful excitement, arising from the *intense illumination of the whole field of view.* And here, in fact, lies the great practical inconvenience of the present method; for, to take a common case—an object about 1-300th of an inch in diameter being placed in the middle of the field of view, the diameter of which is about 1-12th of an inch, and consequently being 1-625th part of the area of the field of view, the eye has to contend with 624 parts of bright light, which are not brought to bear upon the illumination of the object. Hence, a method by which this intense glare shall be wholly removed, and that without the loss of a single effective ray, must evidently be superior to the one usually employed, in the ratio of at least 600 to 1.

Being lately engaged in the examination of a few *test objects,* I happened to notice that the feathers of the *Lycæna argus,* when held above the flame of a candle, exhibited at a certain angle all their peculiar tints, and at the same time the flame was not visible to the eye. It then occurred to me, that by preserving the same angle under the microscope, the advantages of amplification would also be accompanied by the natural colours of the object. The requisite angle was readily obtained by making the axis of the microscope coincide with the line from the object to the eye, while the candle and the object retained

their relative positions. The result accorded with my antici-pation, and I was gratified by the exhibition of the most brilliant diamond tints, sparkling with exquisite lustre *on a jet-black ground.* This new method of illuminating micros-copic objects, it is at once apparent, consists in obtaining *oblique refracted light.*

On submitting a series of objects to the same illumination, I was soon convinced of the value of the discovery; and I scarcely know which to admire most—whether the very natu-ral appearances of objects, adorned, as they invariably are, by the presence of their most delicate colouring, or the personal comfort of the observer, arising from the absence of all super-fluous light. To illustrate the two methods by a reference to the telescope, it may be observed, that the discomfort of view-ing spots on the sun not unaptly corresponds with the view of miscroscopic objects on an illuminated field; while the re-moval of all inconvenient and ineffective light from the field of the miscroscope corresponds with the clear and quiet view of stars on the dark blue vault of the firmament.

The most practicable mode of obtaining the illumination now described is to fix the object on the stage of the miscros-cope, in the usual way, the axis of which must be inclined to the table, at about an angle of 45°, and then to place the candle about two inches below the stage, and about one or two inches to the right or left of it; but this lateral distance must be varied, according to the nature of the object and the angle of aperture of the instrument. It must be carefully borne in mind that the illumination will not be correct unless the field of view be *wholly darkened.*

To obtain this kind of illumination with facility and effect, it will be necessary to make some alterations in the construction of the instrument: as, for instance, in order to apply condensed light, the arm of the condenser must be placed in a ball-and-socket joint, or some similar contrivance must be adopted; for when it is

perpendicular to the axis of the microscope, its introduction diverts the course of the rays from the candle to the stage, and not unfrequently illuminates the field of view. The mirror also cannot be made available in its present position, for this kind of illumination, because light, when reflected from it, must of necessity illuminate the field. It must therefore be fixed on an extended and jointed arm; and when so constructed, microscopic objects may be viewed even in the daytime by oblique refracted light. Again, a very remarkable microscopic effect will be produced by giving a small vertical angular motion either to the body of the instrument or to the stage, as in Goring's Engiscope*. By this means, the plane of the object which, owing to the present construction, is of necessity parallel to the diameter of the object-glass, may be inclined to it at different angles; and we shall thus obtain *oblique vision* as well as *oblique illumination.* These two conditions are absolutely necessary for obtaining, in many instances, the true effect of coloured objects even with the naked eye, and the introduction of magnifying powers between the object and the eye does not render these two conditions a whit the less necessary.

The effect of this new method of illumination may be tried with advantage on various subjects of the larger kind, as cuttings of wood, scales of fish, and wings of insects†. We may also apply it, with peculiar interest, to the investigation of the elementary organs of plants; animal tissues; mosses; corallines; crystals; and the scales of insects of the orders Lepidoptera and Thysanura. In each and all of these some striking and hitherto unperceived character will be developed, and the observer will rise from his pursuit with a more thorough

* See Microscopic Illustrations, page 39, fig. 1 and 9.

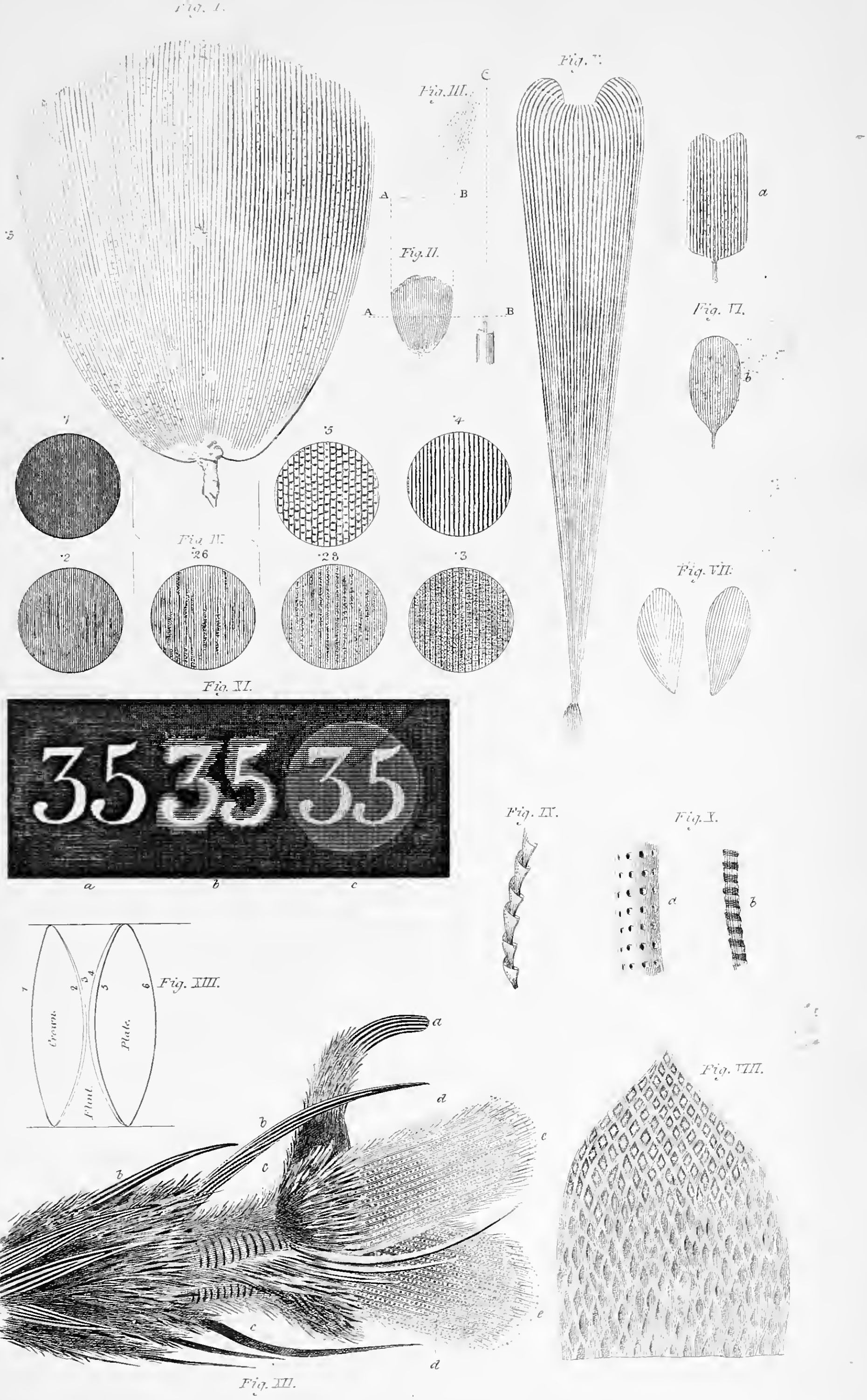
† Among the various objects which shew the superiority of this kind of illumination over transmitted light, the spiral vessels of the hyacinth and the pollen of the convolvolus major are the most decided.—A. P.

persuasion that the Being whose word is power, and by whom his own body "is fearfully and wonderfully made," has equally exhibited the matchless efforts of his skill in the exquisite polish of an insect's joints; in the opening of a leaf; and the pencilling of a flower.—To be a theoretical atheist is impossible.

Peckham, Nov. 1836.

THE END.

Wilson and Son, Printers, 57, Skinner-Street, London.



C. [illegible] Goring del.

T. Bradley sculp.

Pubd. Jan: 183[illegible], by J. Murray, Albemarle Street.

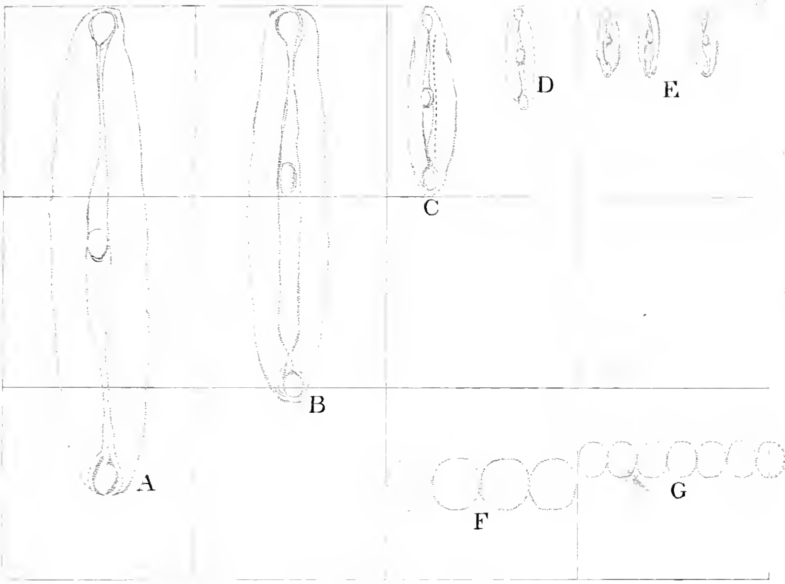


Fig 1.

Fig. 2.

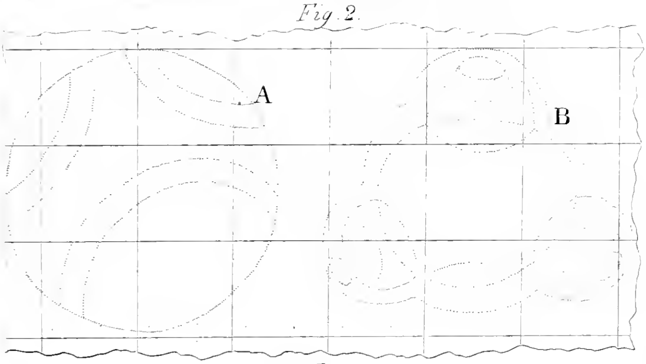
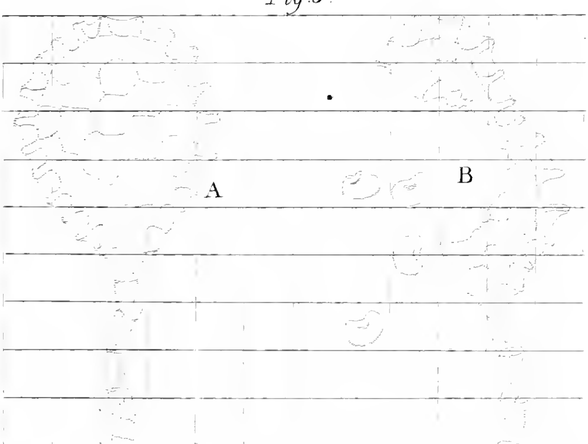


Fig. 3.



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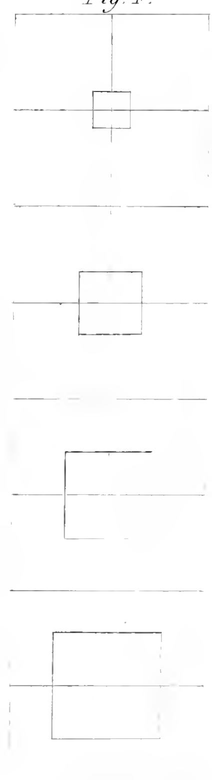

London. Whittaker & C° Jan. 1857.